Ways to understand and measure bushmeat hunting to improve targeting of conservation interventions: a case study of the GolaMA project, Liberia

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ABSTRACT

Over-hunting is a major driver of biodiversity loss and threatens people's food security and livelihoods worldwide. I describe a rural hunting system at a conservation project site in Gola, Liberia, and explore how social science tools can help conservationists understand and influence human behaviour.

In marketing, the technique of 'audience segmentation' is used to identify which specific group of people will be targeted by a campaign. I applied audience segmentation to differentiate hunters, identifying distinct hunter types that differed according to livelihood portfolios, hunting methods, citizenship (indigenous locals or non-locals) and previous experience of law enforcement. Results suggested that interventions should seek to target specific groups, for instance, programmes to support income from cocoa farming could be appropriate for local trappers with cocoa farms, but not for non-local gun-hunters who did not own plantations.

Measuring people's behaviour is challenging where activities are illegal and could be under-reported. I evaluated hunting and trading over a two-year period using the bean method, a technique designed to encourage truthful reporting by ensuring people's answers remain anonymous. Results indicated a decrease in bushmeat trading from 36% to 20% of households, but little change in hunting. Most respondents (>90%) gave direct answers that were consistent with bean method answers, suggesting questions were not sensitive despite conservation interventions aiming to reduce hunting. The technique was low-cost and straightforward to implement.

Harvest datasets are fundamental for understanding hunting systems but are susceptible to sampling and measurement biases. I compared catch-per-day from two methods, hunter recall interviews and village-based monitoring, revealing a two-fold difference in estimates. Results suggest non-random sampling of hunters' or hunting trips could be a major source of bias in harvest datasets. Conservation interventions can be improved by better targeting of interventions, supported by robust tools to measure resource-use behaviour.

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Chapters included as co-authored publications

This thesis includes four data chapters, three of which are included as jointly authored publications, and one of which is a slightly modified form of a jointly authored publication. Published chapters are included in the final published form. Page numbering follows the numbering of each respective journal.

Chapter 3. *This chapter is a replication of:*

Jones, S., Papworth, S., Keane, A., St John, F., Smith, E., Flomo, A., Nyamunue, Z., Vickery, J., 2019. Incentives and social relationships of hunters and traders in a Liberian bushmeat system. Biol. Conserv. 237, 338–347. https://doi.org/10.1016/j.biocon.2019.06.006

Chapter 4. *This chapter is a replication of:*

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Chapter 5. *This work is also published (with minor differences) as:*

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Chapter 6. *This chapter is a replication of*

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I made the principal contribution to all chapters, and lead on research conceptualisation and survey design, training and coordinating a team of data collectors, data entry and analysis, interpretation of results and writing. Co-authors contributions were:

S. Papworth, A. Keane, F St. John and J. Vickery provided support and advice across all aspects of the work in their capacity as my academic supervisors, and provided comments and editorial suggestions on manuscript drafts (all chapters).

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Summary of findings

This work provides the first detailed description of a tropical forest hunting system in rural Liberia and advances practical tools to support monitoring and targeting of conservation interventions. I conducted the research in Gola Forest, West Liberia, at the site of the GolaMA conservation project, a 5-year programme aiming to reduce over-hunting of forest wildlife. GolaMA was implemented by the Royal Society for the Protection of Birds and the Society for the Conservation of Nature of Liberia, in partnership with the Forestry Development Authority of Liberia, from 2014 to 2019. The project worked with two clans to establish legally recognised community-managed forests and supported the development of sustainable land-use plans which included hunting regulations. GolaMA also aimed to improve income from non-bushmeat sources, and provided livelihood support programmes such as agricultural training, introduction of bee-keeping, and a small loans scheme.

To understand bushmeat hunting and trading at the site, I conducted interviews with hunters (n=205), traders (n=50) and households (n=476 in 2017, n=523 in 2019) between July 2016 and July 2019. Respondents included participants and non-participants of GolaMA interventions. Bushmeat played a major role in local livelihoods: it provided income for up to 40% of households and was the principal or only income source for 74% of hunters and 78% of traders, many of whom were women. Perceived bushmeat incomes of US$120-260/month were high relative to other income sources, underscoring the challenge of designing effective livelihood-based interventions, particularly for vulnerable groups such as female traders. Hunters and traders were motivated to change their behaviour by different factors: traders were concerned with risks of bushmeat confiscation at roadblocks, while hunters cited time demands of agricultural activities as a principal constraint on hunting. The range of financial incentives, motivations and social influences suggested that livelihood-based approaches could be targeted strategically to maximise socio-economic and conservation impact.

I examined how interventions to reduce hunting could be effectively targeted by applying the marketing technique of audience segmentation to identify key groups within the population. Cluster analysis based on socio-demographic, livelihood and behavioural variables provided a way to distinguish distinct hunter types that differed in terms of livelihood portfolios, hunting methods, citizenship (indigenous locals or non-locals) and previous experience of law enforcement. The profiles of these groups suggested interventions could be targeted effectively. For instance, programmes to support income from cocoa farming could be appropriate for local trappers with cocoa farms, but not for a large group of non-local gun-hunters who did not own plantations.

Once interventions are designed and implemented, measuring patterns of behaviour is often challenging where activities are illegal and could be under-reported. I used the "bean method", which is designed to minimise misreporting of potentially sensitive behaviour by allowing respondents to answer straightforward questions without revealing their response to an interviewer. Answers are given by placing a coloured bean in a jar with a known number of beans in it, with the colour of bean denoting an answer (e.g. 'yes' or 'no'). Beans are counted after a survey-day to obtain group-level estimates. I assessed hunting and trading in households that did and did not participate in GolaMA, over a 2-year period. Bean method results agreed closely to when people were asked the same questions directly, for all groups. Results revealed a decrease in trading activity across project and non-project households from 36% to 20%, while hunting decreased only in one project group (38% to 28%). Alongside anecdotal reports, these results provided evidence that law enforcement at a roadblock had acted as an effective deterrent for some traders. The bean method was straightforward to implement and could be adapted to suit a wide range of conservation settings.

I examined sources of error in hunting catch data to evaluate how biases could influence monitoring outcomes or management decisions about who to target. Alternative methods to measure hunters' catch produced a twofold difference in estimates of catch per day. Continuous recording of catch by village-based assistants gave a mean estimate of 3.0 animals [2.4-3.6 95%CI] on an average length trip of 3.2 days, whereas asking hunters to recall their most recent catch gave an estimate of 7.3 animals [6.0-8.8] for a trip of the same length. The villages which appeared to have highest catch differed according to survey method. Several potential sources of bias were identified, including representation of long versus short hunting trips, and non-random sampling of hunters.

My work shows hunting-reduction interventions could be improved by focussing on who they aim to influence, social context for behaviour, and techniques to reliably measuring resource use. Future work at GolaMA should seek to identify behavioural responses to interventions and improve understanding of which mechanisms are effective for different types of people. In particular, there is a need to identify livelihood barriers for women and non-local hunters, as well as potential feedback processes between small loans schemes and bushmeat livelihoods. I suggest the technique of audience segmentation could be useful in a wide range of conservation settings to account for heterogeneity in people's behaviour and motivations. Similarly, the 'bean method' was a straightforward, low-cost monitoring tool that is practical in low-literacy settings, and could be useful in a variety of settings.

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Chapter 1. Introduction

The hunting of animals for consumption is considered one of the most significant threats to tropical forest wildlife (Milner-Gulland et al., 2002; Nasi et al., 2008; Ripple et al., 2016) and contributes substantially to rural diets throughout much of the tropics (De Merode et al., 2004; Fa et al., 2003; Rushton et al., 2005). The term 'bushmeat' (or wildmeat), refers to wild animals hunted for consumption and encompasses a huge diversity of species (Cawthorn and Hoffman, 2015). Bushmeat is traded commercially in local, national and international markets, with extraction estimates of 4.9 and 5 million tonnes / year for Neotropical and Central African regions respectively (Fa et al., 2002). Unsustainable levels of hunting have resulted in elevated extinction risks and local defaunation (Fa and Brown, 2009; Ripple et al., 2016), with potential food security consequences for human populations (Cawthorn and Hoffman, 2015) as well as wider ecological impacts (Abernethy et al., 2013; Peres et al., 2016). As such, hunting is considered by many to be an issue of both social and ecological concern and efforts to address it increasingly seek to integrate development goals with conservation aims (Lindsey et al., 2015; Salafsky and Wollenberg, 2000).

A wide range of interventions aim to reduce unsustainable use of tropical forest resources, encompassing the establishment of protected areas (Tranquilli et al., 2014), educational campaigns (Barker et al., 2013; Jenks et al., 2010; Rakotomamonjy et al., 2015), sustainable livelihood promotion (Wicander and Coad, 2018) and financial mechanisms such as conservation payments (Niesten et al., 2010). A widely applied governance framework is community-based natural resource management (Nelson et al., 2007; Nielsen and Meilby, 2015; Pailler et al., 2015), whereby some rights to manage and determine the rules of forest resource use are devolved to the resource users (Brooks et al., 2013). Under this framework, incentives for sustainable management can vary depending on the motivations and opportunity costs for communities of conserving rather than over-exploiting the resource (Souto et al., 2014). Given that over-exploitation can be a financially attractive option (Sayer et al., 2017) community-based management is typically coupled with mechanisms to provide additional incentives or restrictions. These come in a variety of forms that vary in how directly they are linked to conservation outcomes, with examples including co-management with government or non-government bodies (Pailler et al., 2015), payments for specified conservation outcomes (Ingram et al., 2014), financial or development benefits based on adherence to conservation agreements (Niesten et al., 2010), or more general livelihood approaches such as promotion of alternative income sources (Wright et al., 2016). Deciding which of these tools to adopt is complex and challenging (Pullin et al., 2004) and the most appropriate intervention design might depend on site-specific differences in cultural values, socio-economic factors and historical context (Enuoh and Bisong, 2014; Sterling et al., 2017; Walters et al., 2015). For many conservation approaches, the evidence base remains insufficient to effectively guide decisions (Brooks et al., 2013; Burivalova et al., 2019a; Roe et al., 2014). There is a clear need for a more strategic, evidence-driven approach to guide and inform decisions about which types of interventions to implement at a site.

Like most conservation problems, the threats to wildlife from over-hunting can only be addressed by changing people's behaviour (Schultz, 2011). However, many conservationists lack the appropriate understanding, training and skills to do this sensitively and effectively (Robinson et al., 2019; Selinske et al., 2018). A key underlying issue is that interventions are often developed to achieve ecological outcomes and fail to consider the processes that motivate people to act the way they do (St John et al., 2010). Ignorance of the social and cognitive complexities surrounding behavioural decisions can lead to interventions which are at best ineffective (Baynes et al., 2015) and at worse, have unintended consequences (Larrosa et al., 2016). As such, there is a need to advance conservation tools that describe hunting systems from the perspective of resource users, and intervention designs need to be grounded in an understanding of who they aim to influence (Agrawal and Gibson, 1999; Veríssimo, 2013).

In this thesis I explore how a focus on the human behaviour aspects of resource use could help conservationists to: (1) understand social-ecological systems and underlying drivers of resource use; (2) develop more effective behaviour change interventions and; (3) monitor outcomes to assess the impacts of interventions. For each of these processes I consider how techniques and insight from the social sciences could be usefully applied to conservation practices, within the context and constraints of a rural hunting system.

Understanding social-ecological systems from the perspective of resource-users

Conservationists need to understand hunting systems from the perspectives of resource-users in order to design tools that can effectively influence behaviour. To achieve this, researchers and practitioners are increasingly adopting theoretical frameworks and methodologies developed in the psychological and social sciences (Bennett et al., 2016b; Moon and Blackman, 2014; Saunders et al., 2006). Decision-making theories, such as the theory of planned behaviour (Ajzen, 1996), bring to light factors that can underpin behavioural choices, such as attitudes, personal and social norms, and perceived intrinsic or extrinsic barriers. The integration of these frameworks into conservation work has proven useful to identify determinants of behaviours (e.g. Fairbrass et al., 2016; Gurney et al., 2016) and in supporting the design of behaviour change programmes (Martinez et al., 2013; Mastrangelo et al., 2014; Steinmetz et al., 2014), and could contribute to better models of social ecological systems (Schlüter et al., 2017). Cultural values and their social context can be particularly relevant for understanding wildlife use (Etiendem et al., 2011). For instance, taboos against hunting or consuming particular species can affect patterns of exploitation and abundance (Heinicke et al., 2019a), and may change through time due to sociodemographic trends (Jones et al., 2008). Understanding patterns of information flow across social networks can help ensure conservation messages are delivered effectively (Baird and Gray, 2014; de Lange et al., 2019), while social factors such as trust are integral to cooperative, sustainable management of open-access resources (Bouma et al., 2017; Smith et al., 2019; Stern and Baird, 2015). At the level of individuals, variation in cognitive and psychological factors might influence how people respond to different interventions, for instance, attitudes towards risk can affect livelihood decisions (Charness and Gneezy, 2010), while intrinsic motivations can affect the success of payment schemes in promoting a particular behaviour (Nilsson, 2015; Rode et al., 2015).

Previous case-studies of hunting systems have demonstrated that an understanding of socio-cultural context can generate valuable insights into underlying drivers of resource use and potential pathways for sustainable management (e.g. Coad et al., 2013; Kumpel, 2006; Van Vliet et al., 2015). For instance, wildlife consumption patterns can be driven by economic factors, such as the price of other protein sources (Brashares et al., 2004), but also by taste preferences (Mbete et al., 2011), cultural associations with status or wealth (Chausson et al., 2019), perceived health benefits (Chausson et al., 2019), spiritual belief systems (Etiendem et al., 2011; Jenkins et al., 2011), or food-sharing practices that maintain social ties (Van Vliet et al., 2015). Resource use behaviour is affected by political, economic or ecological pressures (Coad et al., 2013; Gill et al., 2012; Yasuoka et al., 2015), and changes through time can be underpinned by shifts in values and attitudes which have long-term consequences for local governance systems (Kaye-Zwiebel and King, 2014). Behavioural perspectives help show that while motivations for hunting are often commercial (e.g. Bachmann et al., 2019; Nielsen and Meilby, 2015), the relationship between hunting and poverty is far from straightforward, and factors such as availability of suitable employment may be more important than material wealth (Travers et al., 2019). It is evident that most hunting systems encompass a diversity of actors who are likely to vary in terms of behaviours, attitudes, values, socio-economic circumstances and experiences (e.g. Coad et al., 2010; Kümpel et al., 2009; Lindsey et al., 2015; Rist et al., 2010). However, conservation approaches tend to treat resource users as a homogenous group, and interventions are often aimed at an "average" person rather than being targeted towards those with the greatest conservation impacts (Agrawal and Gibson, 1999; Olmedo et al., 2017; Spiteri and Nepal, 2006).

Improving intervention designs: targeting specific groups of people

Techniques developed in the world of marketing could help conservationists influence behaviour more effectively (Salazar et al., 2019; Wright et al., 2015). Indeed, the value of marketing tools as a means to promote changes in behaviour has long been recognised by those working in fields such as public health, giving rise to the discipline of 'social marketing' (Kotler and Lee, 2008). Social marketing campaigns are developed from a strong grounding in behavioural theory, using an iterative approach of testing, implementing, monitoring and adapting interventions based on their effectiveness (Mckenzie-Mohr, 2000). Fundamental to this process is defining specifically who the campaign seeks to influence and using their perspectives and motivations as the basis for intervention design (Mckenzie-Mohr, 2000). Social marketing has been successfully used in public health (Gordon et al., 2006; Hastings, 2007) and to address environmental issues (Hargreaves, 2011; Peattie and Peattie, 2009) but has been applied less frequently to biodiversity conservation (Veríssimo, 2019). Exceptional examples are the Pride campaigns of the RARE Centre for Behaviour and the Environment, which have been using social marketing to address conservation issues worldwide for the past 30 years (Green et al., 2019; Jenks et al., 2010; Salazar et al., 2019). For instance, Salazar et al. (2019) describe how a Pride campaign promoting messages about conservation of a parrot species, *Amazona barbadensis,* contributed to its population increase, improving people's awareness and compliance with regulations, and shifting social norms. Several authors have made compelling arguments that social marketing principles could be better integrated into conservation practice. For example, marketing techniques might improve campaigns using flagship species to garner support for conservation (Verissimo et al., 2011), efforts to reduce human-wildlife conflict (Veríssimo et al., 2019), demand-reduction campaigns to address illegal wildlife trade (Greenfield and Veríssimo, 2019), and the way conservation messages are communicated (Kidd et al., 2019).

An important insight from social marketing is that behaviour change interventions might be improved if they are targeted toward specific groups within society (Kidd et al., 2019; Verissimo et al., 2011), a view which is supported by observations of hunting systems (e.g. Coad et al., 2013). Reviews of conservation campaigns suggest that conservationists often fall short of standard marketing practice when it comes to defining who they intend to influence (Greenfield and Veríssimo, 2019; Kidd et al., 2019). Conservation programmes may be designed without identifying a target group (Olmedo et al., 2017) or doing so in vague terms (Agrawal and Gibson, 1999; Spiteri and Nepal, 2006), whereas marketers devote substantial attention and resources into defining who a campaign is aimed at (e.g. Schmid et al., 2008). This tendency in conservation to adopt a "one-size-fits-all" approach is part of a wider problem of failing to strategically plan behaviour-change interventions (Schultz, 2011). For instance, in campaigns to reduce rhino horn demand, target groups were broadly defined, such as encompassing 'the general public', and differed between organisations (Olmedo et al., 2017). Campaigns also lacked a clear purpose, for instance, whether the intention was to "raise awareness" or "reduce demand" (Olmedo et al., 2017). Moving towards standard practices which place humans and their behaviour at the core of intervention design, and using this to target specific groups, could be an effective way forward for biodiversity conservation (Salazar et al., 2019).

A promising tool for targeting behavioural interventions is the marketing technique of "audience segmentation". In marketing, the term audience segmentation describes the process of differentiating a general population according to peoples' characteristics, such as behavioural, demographic or socio-economic profiles. The aim is to identify groups that are expected to be internally homogenous in their response to behaviour change interventions, but which differ from one another in terms of the interventions that are most effective (Schmid et al., 2008). Identifying and profiling these clusters can enable the design of behaviour change tools that are optimal for specific groups (Schmid et al., 2008). The factors used to identify groups is paramount, and marketers may incorporate a large range of socio-demographic variables, as well as psychological traits, such as risk attitudes and personality, which can mediate decision-making (Barber et al., 2012). While psychological profiles of resource-users may be hard to obtain in many conservation settings, attributes such as livelihoods, demography, economic status and harvesting behaviour might offer a practical basis to define target groups. Hunters can differ substantially in terms of their impacts on wildlife (Kümpel et al., 2009), their financial and non-financial motivations (Carvalho et al., 2014; Chang et al., 2019) and the barriers they face for adopting new livelihood strategies (Wicander and Coad, 2018). The technique of audience segmentation might be a useful approach to better understand the full range of behavioural, sociodemographic and livelihood profiles at a site, and develop behaviour change mechanisms which effectively target different groups.

Monitoring behaviour and resource use

To effectively influence behaviour, targeting needs to be coupled with an understanding of which interventions work best for which types of people. However, evidence that interventions have been successful in influencing resource use behaviour is often of poor quality and provides a mixed picture (Brooks et al., 2013; Burivalova et al., 2019a; Hajjar et al., 2016; Ingram et al., 2014). Consequently, more robust studies are needed to build an evidence base that can guide decision-making (Burivalova et al., 2019b). While a growing body of work shows positive impacts of protected area management and law-enforcement as a conservation tool (Coad et al., 2015; Ferraro and Hanauer, 2015), the general effectiveness of community-based management for achieving either conservation or social development aims remains unclear (Bank and Sills, 2014; Baynes et al., 2015; Galvin et al., 2018; Keane et al., 2019; Roe et al., 2014; Terborgh and Peres, 2017; Travers et al., 2015). Empirical support for livelihood-based approaches is particularly sparse (Brooks et al., 2013; Roe et al., 2014) and the processes by which livelihood interventions are intended to operate are often poorly thought-through (Spiteri and Nepal, 2006; Wright et al., 2016). One problem is that community-based management often aims to achieve multiple outcomes, and these may be hard to measure accurately (Burivalova et al., 2019a; Cook and Hockings, 2011; Hajjar et al., 2016).

In many cases, interview-based surveys can represent a practical and cost-effective means to monitor behaviour. However, reported behaviour is susceptible to social desirability bias, where people may avoid sharing information that is incriminating or presents them unfavourably, or exaggerate reporting of socially accepted acts (Krumpal, 2013). Therefore it can be particularly challenging to measure activities that are illegal or illicit, due to inaccurate or non-reporting by those unwilling to share potentially incriminating information (Gavin et al., 2010; Krumpal, 2013). Ways to minimise social desirability bias include specialised survey methods that encourage truthful responses by ensuring researchers cannot directly link behaviour to individuals (Nuno and St. John, 2015). These have provided higher prevalence estimates of non-compliance with conservation rules where the issue is sensitive (Conteh et al., 2014; Fairbrass et al., 2016; Razafimanahaka et al., 2012; St John et al., 2012) but can come at a cost of statistical efficiency (Hinsley et al., 2019) and some perform poorly with small sample sizes or for behaviours with low prevalence (Hinsley et al., 2019; St John et al., 2018). Well known techniques which have been used to reveal patterns of illegal hunting include the unmatched count technique (Hinsley et al., 2019) and randomised response technique (Razafimanahaka et al., 2012). The former involves asking respondents to indicate how many items on a list they have participated in, with half of the sample being shown a list that includes the sensitive behaviour. This approach was used by Harrison et al., (2015) to investigate socio-economic patterns of illegal resource use in Uganda, and by Nuno et al (2013) to identify spatial and socio-economic patterns of poaching in Tanzania. The randomised response technique uses a randomising device, such as dice, to mask respondents' true answers. For example, respondents could be instructed to answer a sensitive question with the word "yes" if they roll a 1, "no" if they roll a 6, and otherwise to answer either yes or no truthfully. Interviewers do not see the dice roll but can analyse results based on the known probabilities of the randomising device. This technique has been applied in several studies to understand drivers and patterns of wildlife hunting and consumption (Chang et al., 2019; Razafimanahaka et al., 2012; Solomon et al., 2007; St John et al., 2012).

Specialised techniques can have drawbacks which may make them inappropriate if a behaviour is not highly sensitive, where financial or time constraints are limiting, or if managers lack statistical expertise (Danielsen et al., 2014; Hinsley et al., 2019). A pragmatic solution may be a technique developed by Lau et al. (2011), which uses a straightforward voting system to help gauge social desirability bias. Known as the “bean method”, respondents are asked to give their answer by placing a coloured bean in a jar which already has a number of beans. The colour of the bean denotes whether the answer is yes or no, and interviewers only count the beans at the end of each day, to give group level prevalence estimates. Differences between direct answers and those given through the bean method indicate under- or over- reporting which is presumed to be attributable to sensitivity of the question. This technique could be a useful monitoring tool in community-based resource management, being relatively simple, and potentially less costly or demanding to implement and interpret than other specialised approaches. However, the bean method has yet to be applied in site-based conservation settings.

Assessing the quality of data that describes hunting behaviour

In hunting systems, information about hunters’ catch and effort is central to understanding patterns of hunter behaviour (Sirén et al., 2013), economic motivations (Golden et al., 2014), ecological impacts (Bobo et al., 2015) and for evaluating conservation success. Harvest data may help managers identify appropriate target groups, and design interventions that effectively address threats to wildlife (Borgerson, 2016). Furthermore, metrics based on catch per unit effort or prey composition can provide low-cost monitoring tools in community-based management (Marrocoli et al., 2019; Yasuoka et al., 2015), and reveal patterns at large spatial or temporal scales (Ávila et al., 2017; Ingram et al., 2015). However, catch per unit effort has several well-documented limitations as a monitoring tool (Keane et al., 2011; Maunder et al., 2006; Rist et al., 2008). For instance, relationships between catch, effort and prey populations may be complex, and effort is difficult to define appropriately (Dobson et al., 2019; Rist et al., 2008). More generally, survey methods to collect catch data are susceptible to several sources of bias which need to be quantified to interpret patterns appropriately. Data quality may suffer from non-representative sampling (St John et al., 2014), inaccurate reporting, error in recalling past events (Golden et al., 2013; Jones et al., 2008), or variation in how questions are interpreted. Survey design details, such as the timeframes being examined (Golden et al., 2013; Jenkins et al., 2011; Jones et al., 2008) or the point along the market chain that observations are made (Crookes et al., 2005), can also affect results. Sources of bias are likely to change through time due to shifts in hunting practices, ecological patterns, social trends and political contexts (Coad et al., 2013; Gill et al., 2012). It is therefore important to evaluate how different methods and sampling approaches can affect the type of information that is likely to be reported, and the consequences this could have for results used to guide management decisions.

Overall aims and structure

There is a need to improve the impact of conservation interventions which aim to influence resource-use and to develop cost-effective monitoring tools that measure behaviour from the perspective of human decision-making (Crookes et al., 2005; Sommerville et al., 2010). Effective approaches are likely to be based on a good understanding of the social context for behaviours, a clear definition who is to be targeted so that intervention design can be informed by target group profiles, and robust monitoring of behavioural outcomes. This thesis explores these topics and aims to advance practical tools for conservation, using a case-study of a hunting system in rural Liberia.

Chapter 2 Provides an overall background and description of the study site.

Chapter 3 Aims to describe the structure of the bushmeat trading system from a social, economic and livelihood perspective. I apply a mixed methods approach to describe sales and consumption of bushmeat, the role of bushmeat income to livelihoods, financial motivations to hunt or trade, perceived disincentives for hunting and trading and inter-personal relationships between hunters and traders.

Chapter 4 Aims to evaluate “audience segmentation” as a tool for designing hunting reduction interventions that are more effectively targeted toward specific types of resource users. I compare alternative approaches to identify potential target groups: a cluster analysis which incorporates information about livelihoods and hunting behaviour; and a simplistic approach that considers only hunting offtake as a basis for defining target groups. I apply these segmentation approaches to hunters and households and explore how effectively they differentiate groups with distinct profiles that could be targeted with behaviour-change interventions.

Chapter 5 Aims to develop an appropriate monitoring tool for assessing change in hunting behaviour. I apply a specialised questioning technique, the “bean method”, designed to minimise the problem of social desirability bias which can affect the quality of behaviour data. I use the bean method alongside direct questions to assess change in prevalence of bushmeat hunting and trading following implementation of conservation interventions.

Chapter 6 Aims to evaluate potential extent of bias in harvest data introduced by differences between data collection methods. I compare estimates of catch per day from two survey methods: face to face interviews in which hunters report their catch from the most recent hunting trip; and continuous monitoring of a subset of hunters by village-based assistants.

Chapter 7 Provides a discussion of the findings. I discuss implications of my results for conservation management at the study site and offer some recommendations for managers going forward. I then discuss how the tools and approaches evaluated in my work could be contribute to conservation practices more generally.

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Chapter 2. Background to the study site and the GolaMA project

This study was carried out in the Gola Forest, West Liberia, at the site of an EU-funded conservation project titled "Securing Liberian forest connectivity through community forest management and innovative financing mechanisms", or GolaMA, which stands for "Gola Management Agreement". This project, which was implemented by the Royal Society for the Protection of Birds and the Society for Conservation of Nature of Liberia, aimed to achieve biodiversity conservation by establishing community-based forest management over approximately 400km² of lowland forest. A principal focus of GolaMA was reduction of bushmeat hunting to sustainable levels, as high levels of hunting pressure were seen to be a major threat to wildlife populations. Prior to conducting the doctoral research presented here, I worked for the GolaMA project as a field-based researcher and had been living in the study site for approximately 18 months. In the following chapter, I provide a brief background into bushmeat hunting and conservation interventions in Liberia, then I describe the study site in terms of livelihoods, resource management and threats of hunting to wildlife. I finish with an overview of the survey design and data collection methods.

Hunting and wildlife conservation in Liberia

Bushmeat is consumed across Liberia (Junker et al., 2015b; Ordaz-Németh et al., 2017) and commercial trade of dried bushmeat can provide a profitable source of income (Greengrass, 2016; Hoyt, 2004), playing a potentially large role in the country's economy (Hoyt, 2004). Animals are killed by hunters using snares or shotguns and the carcasses then may be consumed or sold locally, or dried and transported to urban markets, often by a trader who buys bushmeat from several hunters. In larger towns and cities, market sellers and restaurateurs may buy bushmeat to prepare and sell to consumers (Bakarr et al., 2009). Bushmeat is an important natural resource for rural populations in low-income settings (Fa et al., 2003). Liberia ranks 176 out of 189 countries according to the Human Development Index (UNDP, 2019); in 2013 almost two thirds of the population lived in multidimensional poverty, and about 50% were considered to live in severe poverty (UNDP, 2019). Hunting can therefore be an important livelihood option where few alternatives are available, particularly since it does not need large investments of capital (cable for snares can be bought cheaply and shotguns can be purchased for US$60, *pers obs*), and skills can be learnt relatively easily.

A wide range of species are hunted for bushmeat in Liberia, encompassing most medium to large-bodied mammals, reptiles and birds (Junker et al., 2015a; Ordaz-Németh et al., 2017). Among the most commonly hunted groups are forest ungulates, such as duikers, and primates. However, the list of bushmeat species also includes pangolins, bats, snakes, forest crocodiles, hornbills, vultures, leopards, elephants and rodents, such as porcupines and squirrels (Buij et al., 2015; Covey and McGraw, 2014; Greengrass, 2016). Many species hunted in Liberia are endemic to the Guinean Forests of West Africa biodiversity hotspot (Mittermeier, 2004) and globally threatened with extinction. This forest habitat, which once extended from Sierra Leone to Togo, has rapidly declined in recent decades (Junker et al., 2012) with Liberia retaining about half the remaining forest habitat (Junker et al., 2015a). Consequently, the country supports globally significant populations of forest wildlife, for instance, among the only remaining viable populations of Western chimpanzee (*Pan troglodytes verus*) (Heinicke et al., 2019b) and pygmy hippopotamus (*Choeropsis liberiensis*) (Mallon *et al.* 2011). The remaining forest cover in Liberia occurs largely within two major forest blocks: the largest is situated in the South-East of the country, extending to the border with Ivory coast; while a second area in the North-West extends from the Sierra Leonean border towards Guinea. The Gola forest, where this study was conducted, constitutes a large portion of this latter forest area.

Degradation and loss of forest habitats continues to pose a threat to Liberia's biodiversity, due to commercial and non-commercial activities such as logging, conversion to palm oil plantations, mining and small-holder agriculture. To counter such threats, conservation strategy in Liberia has focussed on the establishment and management of protected areas, alongside laws to regulate hunting. Liberia currently has 10 protected areas, covering about 4% of the country (UNEP-WCMC & IUCN, 2020) which vary in terms of the resources available for active management. Hunting of wildlife is prohibited within protected areas and enforcement is enacted by forest rangers during patrols or through confiscation of bushmeat at road-blocks near park boundaries. However, resources for law enforcement varies between protected areas and all protected areas are under-staffed (*pers obs*). Despite this, sites that receive external support and funding, such as Sapo National Park, are able to enact regular ranger patrols, although for many sites law enforcement remains a challenge (*pers obs*). Interventions to support livelihoods of forest edge communities, and involvement of local people in forest protection roles, such as 'Eco-guards' (WCF, 2014), are increasingly being used as key tools for protected area management in Liberia. Unfortunately, despite significant progress in recent years, protected areas remain vastly under-resourced and illegal activities such as hunting and mining remain a widespread issue and source of conflict (e.g. Greengrass, 2016).

Beyond protected area boundaries, Liberia's laws prohibit harming or selling protected species anywhere in the country (National Wildlife Conservation and Protected Area Management Law, 2016). Species that are protected include: all those listed as globally threatened according to the IUCN redlist (www.iucnredlist.org); species with restrictions on international trade under CITES (www.cites.org), as well as all diurnal primates. Technically, all hunting requires a license under Liberian law. However, a licensing system is yet to be put in place, so this is not enforceable. Bushmeat from illegally killed species may be confiscated during transport to urban markets, typically at road-blocks situated along major roads. While progress is being made, bushmeat hunting and trade of protected and non-protected species remains widespread and openly practiced across the country. For instance, protected species are often sold openly in markets or roadsides and few people in rural areas are aware of protected species laws (*pers. obs;* GolaMA, unpublished).

Governance and Community-based Forest Management

To adequately address both the conservation and livelihood consequences of over-hunting, changes to natural resource use need to take place outside protected area boundaries (Junker et al., 2015a). In Liberia, community-based forest management could be an appropriate way to achieve this. The Community Forest Rights Law (2009) provides a mechanism by which communities can establish use-rights over a demarcated 'community forest' which can be governed according to land-use management plans that are approved by the central government. Communities can choose between commercial or conservation-oriented management approaches, and the government ratifies management plans on a five-yearly basis. There is growing interest in the potential role of community forests for conservation (A. Gardner *pers. comm.*), with the GolaMA project representing one of the first case-studies for establishment of community forests as a tool for both landscape conservation and socio-economic development.

The community-based management framework reflects the wider governance system in Liberia whereby customary laws and governance institutions sit alongside those of a central government (Tokpa & Yengbeh, 2012). Liberia is divided into 15 counties, then into districts, which are governed by District Commissioners and District Superintendents that are appointed by the president. Each district encompasses several customary jurisdictions called 'clans', with two or more clans coming together to form a 'chiefdom'. These are traditionally governed by locally elected Clan Chiefs and Paramount Chiefs, respectively. Thus, a district will contain more than one chiefdom and several clans. Any settlement (i.e. a town, village or encampment) will fall within the jurisdiction of a clan, and local affairs are managed by a 'town chief' (sometimes also a 'general town chief') (Tokpa & Yengbeh, 2012). Major local disputes are traditionally settled in a clan headquarters, while issues concerning more than one clan are addressed at the chiefdom headquarters. Status as the headquarters is assigned to settlements based on their historical significance, for example, the original sites established by the ancestors of the present-day occupants of the land. Other settlements have a locally recognised hierarchy based on their history of establishment, such that recently established settlements are referred to as being 'under' an older one. Although customary authorities are not appointed by government, their positions are legally recognised and they receive government salaries.

There are 16 ethnolinguistic groups, or 'tribes', in Liberia, which traditionally were spread across several chiefdoms. In the present day, people from several different tribes can be found living within a chiefdom. Tribes are not linked to specific political structures but remain important socio-cultural groups. For example, people from tribes that do not 'belong' to a given chiefdom generally do not wield local political power. Where migration has resulted in a large diaspora, immigrants may elect a representative from their own tribe to negotiate on their behalf with the local leadership. Historic tensions between tribes can affect present day social conflicts and resource use governance. For instance, in the study site immigrant hunters from a particular tribe were considered to be causing social disturbance and over-harvesting wildlife. This resulted in a decision by the local clan leaders to forcibly drive them off the land, which was done by a group of armed citizens (R. Kpoto, *pers. comm*).

Local governance of natural resources under the community-based management framework is implemented at the level of clans, such that a clan may establish a community forest, which will be managed via a locally appointed 'Community Forest Management Body'. By-laws to govern access and rights to forest resources will be created by the management body, as part of a land-use management plan. The central government's Forestry Development Authority (FDA) are involved throughout the application process, validating the proposed boundaries and management plans. After five years the FDA must ratify that management plans have been followed, and new management plans must be approved after 15 years.

Previous bushmeat research in Liberia

Despite the importance of Liberia's wildlife resources from both a conservation and human welfare perspective (Junker et al., 2015a; Ordaz-Németh et al., 2017), there have been relatively few studies of hunting and bushmeat consumption in the country. This may be partly due to the political and social upheaval caused by a sustained period of civil conflict from 1989 until 2003. Before the war, a small-scale study indicated that most (97%) households in Monrovia consumed bushmeat (Anstey, 1991), and later work reported at least 35 species were hunted for commercial sale, with ungulates being the most common group (Hoyt, 2004). Current levels of exploitation are likely to be unsustainable: for instance a market survey at the Liberia-Ivory Coast border estimated volumes of trade that likely exceeded sustainable yield thresholds for primates, which represented over a third

(37%) of the animals sold (Covey and McGraw, 2014). A study at commercial hunting camps around Sapo National Park documented intense hunting pressure on many threatened species, and estimated that professional hunters could earn upwards of $1000 / month (Greengrass, 2016). A nationwide study conducted in 2012 using interviews and transect surveys, showed that hunting remains a widespread activity that has likely contributed to local extirpation of larger fauna (Junker et al., 2015a; Tweh et al., 2015). More recently, a nationwide consumption survey showed bushmeat remains a key component of rural and urban diets, although consumption decreased slightly during the Ebola outbreak in 2014-15, particularly among poorer households (Ordaz-Németh et al., 2017).

Livelihoods and socio-economic background of the study site

The research I describe in this thesis took place in Kongba district, which has one of the lowest population densities in Liberia (LISGIS, 2008) and remains relatively inaccessible due to poor transport and communication infrastructure (Bulte et al., 2012). Vehicle roads linking the study site to Monrovia were introduced in the 1980's as a consequence of commercial logging operations. Prior to this, aircraft were used to access areas which contained rich diamond deposits (Z. Nyamunue *pers. comm.*). As is typical across rural Liberia, subsistence agriculture is at the centre of local livelihoods, and uses swidden systems that are common to much of West Africa (Ellis, 1998).

Diamond-mining and to a lesser extent, gold-mining, resulted in the establishment of some present-day settlements in the study site, and small-scale mining continues to be a locally important activity which influences socio-demographic patterns (Bulte et al., 2012; Hilson and Van Bockstael, 2011). For instance, miners employ seasonal labourers as diggers, many of whom are temporary migrants from Sierra Leone, resulting in a male-biased gender ratio and relatively high ethnic diversity (Table 1; taken from GolaMA, unpublished). Cash revenues from mining activities, and the need for miners to buy food for their labourers (Hilson and Van Bockstael, 2011), means that small-scale business enterprises selling food, alcohol and other goods can be relatively viable, in contrast to villages without mining (*pers obs*). Some present-day settlements in the study site came about from commercial selective logging operations, which were carried out across much of the district but ceased in the early 1990's due to the civil conflict (A Flomo, *pers. comm.*). During the conflict many villages were abandoned or occupied by fighters, and remote areas in the forest were temporarily inhabited by people who had been displaced (Corriveau-Bourque, 2010; Hilson and Van Bockstael, 2011). Precious minerals mined from the study area were notoriously involved in funding rebel groups and fuelled conflict across both sides of the border, but are now valuable income sources for those with few alternative livelihood options (Hilson and Van Bockstael, 2011).

Commercial bushmeat hunting in the study site dates back to pre-war mining and logging operations and some present-day settlements originated as commercial hunters' camps (Z. Nyamumue, *pers. comm.*). In a pattern typical of tropical forests worldwide (Edwards et al., 2019), these extractive industries generated opportunities for hunters as company employees created a local demand for meat, and transport links to larger urban markets were improved. The years following the end of the war in 2003 saw an influx of immigrants, many coming from more densely populated counties in Liberia (Corriveau-Bourque, 2010). For many affected by the conflict, particularly ex-combatants, activities such as hunting and pitsawyering were among the few available livelihood options (A. Flomo *pers. comm.*). Settlements in the study site which did not originate from logging, mining or hunting activities, are located on historic sites which have been occupied by subsistence farmers for several generations.

Table 1. Socio-demographic summary of the two clans participating in the GolaMA project and in the present research, taken from GolaMA socio-economic survey conducted in 2015-16 (GolaMA, unpublished). Note the male-biased gender ratio and relatively high ethnic and tribal diversity in Clan 2.

	Clan 1	Clan 2
Number of households	230	219
Number of men (over 16 years)	306	355
Number of women (over 16 years)	291	234
Number of children (16 years and under)	495	442
Literacy of adult women	15%	35%
Literacy of adult men	46%	54%
% adults educated at senior high-school level*	6%	12%
% of population who are Christian	26%	48%
% of population who are Muslim	74%	52%
% of population from Liberia	88%	87%
% of population from Sierra Leone	11%	11%
Number of tribes represented	16	19
Three most populous tribes (% population)	Gola (70%) Mende (13%) Gio (5%)	Mandingo (18%) Kissi (18%) Gola (16%)

* this corresponds to having completed at least 9 years in formal education

A socio-economic baseline survey was conducted by GolaMA in 2015-16, across all households from the two clans that participated in this conservation project. These households were all also included in the present study, along with households from additional non-project villages (see below for details). The GolaMA baseline survey showed that for most people, agricultural activities represent the most significant occupation in terms of time spent and income generated, with rice-farming being the major time demand for around 40% of adults (Table 2; GolaMA, unpublished). The survey results also reveal slight differences between the two neighbouring clans that participated in the project (Fig. 1), in terms of natural resources, livelihood patterns and demographic history (GolaMA, unpublished). For instance, small-scale mining was a principal occupation for about 25% of adult men in clan 2, but for fewer than 1% in clan 1. Small business enterprises may represent a more prominent occupation in clan 2 particularly among women, 42% of whom cited it as the most significant income generating activity (GolaMA, unpublished). In clan 1 both men and women were predominantly occupied with agriculture; and plantation crops such as cocoa, coffee and oil palm were more important than in clan 2. These differences reflect the greater prominence of diamond mining in clan 2 and may be linked to the fact that clan 1 is situated further from Monrovia with poorer transport links to the capital. However, for clan 1, bush paths into Sierra Leone facilitate cross-border trade, providing routes for selling cocoa, coffee and palm oil (*pers. obs*).

Local dependence on bushmeat for food and income was reported to be high among villages in the GolaMA project area: hunting contributed to the livelihoods of about 12% of adult males: 9% of men in clan 2 (n=355) and 15% of men in clan 1 (n=306; only one woman reported hunting) (GolaMA, unpublished). As elsewhere in Liberia, hunting activities generally formed part of diverse livelihood strategies and was typically accompanied by other activities such as subsistence agriculture, seasonal farm labour or mining. Overall, 96% of households (n=450) had consumed animal protein in the previous three days, 84% had consumed fish and 50% had consumed bushmeat (clan 2 = 48% of households, n=220, clan 1 = 44%, n=230; GolaMA, unpublished). Besides bushmeat, other meats consumed were locally raised chickens and goats, as well as chicken feet and canned processed meat imported from urban centres. Fish was mainly locally caught, but dried fish imported from the coast was also consumed in some villages (GolaMA, unpublished).

The GolaMA survey also assessed poverty using the Progress out of Poverty Index (developed by the Grameen Bank for Sierra Leone; www.progressoutofpoverty.org; 2003). This provides a household score from 0 to 100, based on factors such as house structure, assets, education and income sources which are linked to likelihood of being within poverty brackets defined by more complex metrics. The results showed an average poverty rate in clan 2 of 50% of households (n=220) likely to fall below the Millenium Development Goal US$1.25/day at 2005 purchase power parity line, and 66% of clan 1 households (GolaMA, unpublished). As elsewhere in Liberia, rates of adult literacy were low, particularly among women, with less than half of adults unable to read or write and only a third of women (Table 1; GolaMA unpublished)

Conservation management across the Gola landscape

The Gola Forest landscape represents one of the largest remaining tracts in Guinean Forests of West Africa biodiversity hotspot, and provides more or less contiguous forest cover from Eastern Sierra Leone through to North-West Liberia (Christie et al., 2007; Myers et al., 2000). Ecologically, the forest supports a rich diversity of lowland forest wildlife, including globally significant populations of endangered species, such as the Pygmy Hippopotamus (*Choeropsis liberiensis,* Hillers, 2013), Western Chimpanzee (*Pan troglodytes verus;* Tweh et al., 2015) and Forest Elephants (ELRECO, 2019). Previous conservation research in the region includes ecological and social studies linked to the two large protected areas which lie across the Liberia-Sierra Leone border (Fig. 1): the Gola Rainforest National Park (GRNP), in Sierra Leone and the Gola Forest National Park in Liberia (e.g. Hillers et al., 2017; Lindsell et al., 2011; Lindsell and Klop, 2013; Voors et al., 2011). Surveys within these protected areas have shown that hunting occurs throughout the forest, both in Sierra Leone and Liberia (Hillers, 2013; Jones et al., 2017; Blasi-Foglietti, 2020).

The GRNP covers 690 Km^2 to the West of the study site in Sierra Leone. The area was first designated as a Forest Reserve for timber extraction in the 1920s, then formally became a National Park in 2010. Its management for conservation has been supported by the Royal Society for the Protection of Birds in partnership with the government of Sierra Leone, since 1990 and the protected area now employs approximately 150 staff. GRNP is actively managed through law enforcement patrols, carried out regularly by 50 rangers, as well as community social development programmes, livelihood support work and environmental education campaigns. Several management interventions are linked to the Parks' carbon accreditation under a Reducing Emissions from Deforestation and Forest Degradation plus (REDD+) scheme and aim to ensure positive social and ecological impacts across 122 villages within a 'leakage belt' around the park boundary (RSPB, 2015; see Fig. 1). The leakage belt is a 4 Km zone around the protected area, in which forest quality and cover is maintained under the REDD+ scheme, to ensure that harmful activities are not merely displaced from the park into the neighbouring forest. Key interventions include direct payments to landowning families and paramount chiefs (Voors et al., 2011), livelihood support projects to promote sustainable land-use, saving and lending schemes, scholarship programmes and a community development fund for chiefdoms around the park edge (RSPB, 2015). Other work includes environmental education and a ‘species champion’ programme (Hillers et al., 2017). Livelihood support programmes focus on agricultural training, and there is an extensive programme to improve incomes from ‘forest-friendly’ cocoa.

Immediately south of the study site is Liberia’s Gola Forest National Park which covers about 790 km² and joins the GRNP to form a transboundary ‘peace park’. The Gola Forest National Park was formally gazetted in 2016. However, active conservation work in the area dates from 2009, when the governments of Liberia and Sierra Leone formally agreed the establishment of the peace park (Hillers, 2013). From 2009 to 2013, ecological surveys, livelihood support projects and environmental awareness-raising activities were carried out by the Royal Society for the Protection of Birds and the Society for the Conservation of Nature of Liberia through the project ‘Across the River—a Transboundary Peace Park for Sierra Leone and Liberia’ (Hillers, 2013). Twenty-five Liberian park rangers were trained during the transboundary project and deployed at a park headquarters. From about 2012 rangers conducted irregular law enforcement patrols in the proposed protected area, and confiscated bushmeat at a road-block being transported to Monrovia. This roadblock is situated on the only vehicle road from the study site to Monrovia, and bushmeat is confiscated regardless of whether it was killed within the protected area, in accordance with regulations prohibiting commercial transportation of more than five carcasses per vehicle. Both patrolling effort and vehicle inspections increased substantially during the present study following the park’s gazettement (in 2016) and subsequent boundary demarcation in 2017 (*pers. obs.*).

The transboundary project implemented livelihood support activities intended to reduce pressure on forest resources, principally a swamp-rice farming programme and livestock-rearing, which involved some of the participants in the present study (Hillers, 2013). Livestock rearing of goats was explicitly intended to provide an alternative to bushmeat both in terms of income and as a protein source. However, anecdotal evidence suggested the approach achieved limited success, as very few participants continued to rear livestock after the project end (*pers obs*). Apparent reasons for this included that the livestock were reported to cause nuisance by eating crops, or that they became sick. Some commentators added that people weren’t ‘serious’ to pursue this livelihood, or didn’t ‘believe’ in livestock raising, suggesting that people preferred to invest time and money in activities for which the risks and returns were already known and familiar. Nevertheless, a few individuals that were fully engaged in the activity were able to generate and sustain profits (*pers. obs*).

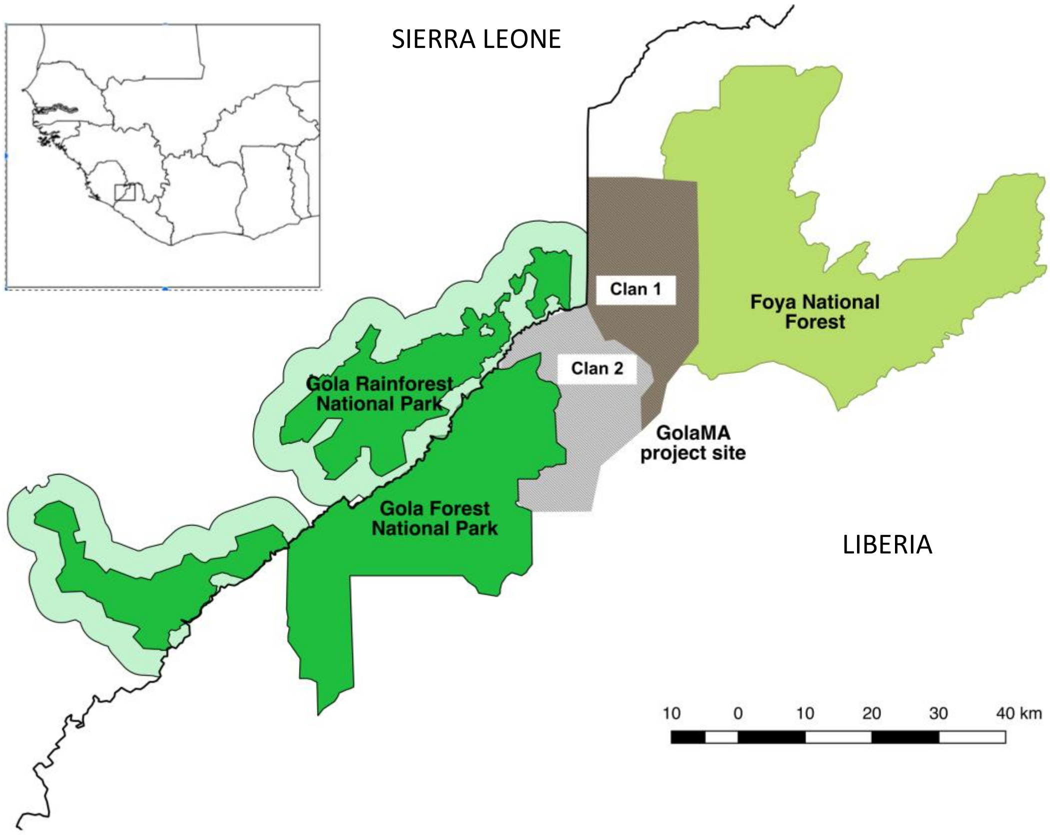

Figure 1. Map showing the GolaMA project site and adjacent protected areas: the Gola Rainforest National Park (GRNP) in Sierra Leone and the Gola Forest National Park in Liberia. The 4Km buffer ('leakage belt') around the GRNP boundary is shown in paler green, indicating the area in which livelihood support work is implemented. Inset shows the location of the study site in West Africa.

Surveys conducted under the transboundary project around the proposed Gola Forest National Park in 2012, revealed communities to be highly dependent on bushmeat and other forest resources for livelihoods (Bulte et al., 2012). Results from 27 forest edge villages (10 of which are included in the present study) showed that many forest-edge villages were extremely remote and lacked access to infrastructure such as roads and healthcare. There was a large number of very small, often temporary, settlements, linked to small-scale mining activities. Lasting socio-demographic effects of civil conflicts in Liberia and Sierra Leone were apparent in the weakening of traditional governance structures, particularly the 'stranger-father' system which traditionally demands that non-locals must seek a local sponsor to access land or extract resources such as wildlife (Corriveau-Bourque, 2010). The authors also noted high levels of suspicion and mistrust towards conservation and protected area management (Bulte et al., 2012).

Table 2 Livelihood activities of adults within the two clans participating in the GolaMA project, adapted from the 2015-16 GolaMA baseline socio-economic survey (GolaMA, *unpublished*). Values are % of adults (over 16 years) for whom the activity was reported as the most or second-most important occupation in terms of time or income.

		Number of individuals interviewed	Number of house-holds	Most important occupation in terms of time	Second most important occupation in terms of time	Most important occupation in terms of income	Second most important occupation in terms of income
Clan 1	Men	306	212	**Rice farmer (53%)** Plantation crops (10%) Mining broker (9%) *[No answer 2%]*	**Rice farmer (23%)** Plantation crops (13%) Garden (10%) *[No answer 25%]*	**Rice farmer (28%)** Plantation crops (23%) Mining broker (11%) *[No answer 5%]*	**Rice farmer (28%)** Garden (11%) Plantation crops (7%) *[No answer 29%]*
	Women	291	210	**Rice farmer (51%)** Garden (22%) Business / trade (17%) *[No answer 2%]*	**Rice farmer (26%)** Garden (24%) Business / trade (13%) *[No answer 30%]*	**Garden (30%)** Rice farmer (29%) Business / trade (25%) *[No answer 9%]*	**Rice farmer (34%)** Garden (14%) Business / trade (8%) *[No answer 41%]*
Clan 2	Men	355	205	**Rice farmer (27%)** Mining digger (24%) Student (9%) *[No answer 1%]*	**Rice farmer (18%)** Garden (13%) Business / trade (9%) *[No answer 36%]*	**Mining digger (25%)** Rice farmer (14%) Business / trade (10%) *[No answer 10%]*	**Rice farmer (22%)** Garden (9%) Business / trade (8%) *[No answer 43%]*
	Women	234	167	**Business / trade (33%)** Rice farmer (31%) Garden (15%) *[No answer 1%]*	**Garden (21%)** Rice farmer (18%) Business / trade (18%) *[No answer 33%]*	**Business / trade (42%)** Garden (23%) Rice farmer (15%) *[No answer 11%]*	**Rice farmer (24%)** Garden (15%) Business / trade (11%) *[No answer 47%]*
Both clans	Men	661	417	**Rice farmer (39%)** Mining digger (13%) Other trade (7%) *[No answer 2%]*	**Rice farmer (20%)** Garden (11%) Plantation crops (7%) *[No answer 31%]*	**Rice farmer (21%)** Mining digger (14%) Plantation crops (12%) *[No answer 8%]*	**Rice farmer (25%)** Garden (10%) Business / trade (6%) *[No answer 37%]*
	Women	525	377	**Rice farmer (42%)** Business / trade (24%) Garden (19%) *[No answer 2%]*	**Garden (23%)** Rice farmer (23%) Business / trade (15%) *[No answer 31%]*	**Business / trade (32%)** Garden (26%) Rice farmer (23%) *[No answer 10%]*	**Rice farmer (29%)** Garden (14%) Business / trade (9%) *[No answer 44%]*

Species conservation in the study site

The forest in and around the study site supports a full diversity of lowland forest species found in the upper Guinea forest biome (Lindsell *et al.* 2011, Tweh *et al.* 2015), and as such, hunting is a concern for populations of several endangered species. These include the Pygmy Hippopotamus (*Choeropsis liberiensis*) and Jentink's duiker (*Cephalophus jentinkii*), both classified as endangered, and the zebra duiker (*C. zebra*) and forest elephant (*Loxodonta cyclotis*) which are listed by the IUCN as vulnerable. There are eight species of diurnal primate found in the study site, all of which are hunted and many of which have rapidly declining global populations. These include the critically endangered Western Chimpanzee (*Pan troglodytes verus*), four endangered monkey species and two that are vulnerable. Comparisons of primate densities between the study site and Gola Rainforest National Park, show the latter has higher densities of threatened monkeys, notably Western red colobus (*Piliocolobus badius*) and Diana monkey (*Cercopithecus diana*) (Blasi-Foglietti, 2020). As the areas are adjacent with similar habitats but differing levels of hunting pressure, this discrepancy likely points to the impacts of hunting (Blasi-Foglietti, 2020). Other threatened species that are vulnerable to hunting include three pangolin species, as well as the critically endangered slender-snouted dwarf crocodile (*Mecistops cataphractus*).

In this study, I focus on hunting for bushmeat, which constitutes the vast majority of hunting activity within the study site. However, markets for other animal products can lead to targeting of particular high value species. Notably, pangolins have recently been exposed to increasingly targeted persecution at the study site, due to the influence of international pangolin scale traffickers (*pers. obs*). Products such as leopards' teeth, crocodile skin, and chimpanzee body parts are also reported to fetch high prices locally (*pers obs*). Elephants are targeted for ivory, but unlike other species, elephants are not likely to be killed opportunistically, but rather only by specialised elephant hunters due to fire-power and skills required. Additionally, due to the high value of ivory, there is more rigorous law enforcement with respect to elephants, evidenced by the recent prosecution in 2019 of an elephant hunter (africanelephantjournal.com).

All of the above-mentioned species are formally protected under Liberian law. However, many hunters in the study site are unaware of the protected status of species (GolaMA, unpublished), with the likely exception of forest elephants, and hunting methods such as snares are often largely indiscriminate. As such, there is no evidence that hunters' prey selection is substantially influenced by whether or not a species is protected. There are also several bushmeat species that are not currently endangered and are not listed as nationally protected. These include species that have relatively widespread distributions, such as the Maxwell's duiker (*Philantomba maxwelli*), as well as species that are tolerant (or even pests) of agricultural habitats such as the greater cane rat (*Thryonomys swinderianus*) and bushbuck (*Tragelaphus scriptus*). In the study site, it was prohibited to transport over five carcasses in a single vehicle, and confiscation at checkpoints was the only form of enforcement of hunting laws that applied to hunters operating outside protected area boundaries. As such, hunters could expect the same penalties whether or not species were formally protected, with the exception of ivory confiscation, reducing incentives to avoid killing protected animals.

The GolaMA project

The GolaMA project was Funded by the European Union, under the full title "Ensuring Liberian forest connectivity through community-based management and innovative financing mechanisms", and it ran from December 2013 to December 2019. GolaMA stands for 'Gola Management Agreement' and is a word in the Lorma language meaning 'unity'. The project was implemented by the Royal Society for the Protection of Birds and the Society for the Conservation of Nature of Liberia, building on relationships that had been established with communities during previous work under the project, 'Across the River – a transboundary peace park for Liberia and Sierra Leone'. The GolaMA project aimed to secure conservation of forest area that connects with the northern sectors of protected areas in Liberia and Sierra Leone (Fig 1), using a framework of community-based natural resource management. Due to the outbreak of Ebola virus in the region, field activities were delayed from the project start until March 2015.

The GolaMA project worked with 16 villages belonging to two clans, in Kongba district, encompassing approximately 430 households. Activities focussed on supporting each of the two participating clans to establish 'community forests', under Liberia's Community Forest Rights Law (2009). These community forests would be managed based on conservation land use plans approved by the government's Forestry Development Authority, and revised every five years. The final agreement of community forest management plans took place after the completion of this study, in November 2019. This saw each clan create hunting regulations which will be implemented by community 'eco-guards' (GolaMA end of project report, in prep).

In addition to the goal of sustainable forest resource management, GolaMA aimed to contribute positively to local livelihoods and socio-economic development. The project implemented several types of livelihood support programmes from 2015 to 2019, which included the introduction of bee-keeping, agricultural training programmes, a small loans scheme, and adult literacy classes. Agricultural support included a programme to develop swamp farming techniques for crops such as rice, a programme to improve yields from cocoa through farmer training schemes and provision of high yielding cocoa seed, and support for farmer collectives through the provision of seeds for crops such as peanuts and beans. The small loans scheme offered local residents (organised into loan groups) access to credit for which interest was partly paid through contributing time or labour to conservation action such as conducting environmental education campaigns. Members of loan groups were not required to specify the purposes for which loans would be used, but loan groups signed a memorandum of understanding that none of their members would use loans for activities relating to hunting or trading wildlife. Livelihood support programmes were typically implemented gradually, with 'trial' phases during which the activity was carried out on a small-scale to identify any issues before full-scale implementation began (Fig 2). The project also sought to improve incomes from small-scale mining, the environmental impacts of which are considered limited at the GolaMA site and held discussions with local miners around interventions such as provision of equipment for local mining groups alongside improvements to mining methods intended limit ecological degradation from digging of mining pits. Participation in all the above programmes was accompanied by formal agreements to refrain from hunting or trading of bushmeat.

Methods

Rationale for the survey design

Data collection for this study was designed with the dual aim of exploring research questions outlined in Chapter 1 and supporting implementation of the GolaMA project. Thus, survey methodology aimed to achieve the following:

1) develop understanding of the bushmeat system from the perspectives of hunters and traders: with a focus on the livelihood role of bushmeat hunting and trading and peoples' incentives or disincentives.
2) develop understanding of which species were affected by hunting and approximate levels of harvest.
3) gain insights into who was engaged in hunting and trading, their livelihood profiles and variability in levels of resource use to help identify the target group(s) for project interventions.
4) evaluate the prevalence of hunting and trading among households at the start and end of the project.
5) develop tools that might be suitable for post-project monitoring of hunting and trading by community forest management bodies.

Additional key considerations were minimisation of survey costs such as travel to remote villages and the risks of respondent fatigue.

To fulfil the above criteria, three questionnaire-based surveys were developed, a household survey, a hunter survey and a trader survey, as well as a village-based offtake survey to record hunters catch (Table 3). Focus group discussions were also carried out with hunters and traders to give broader context about these activities (see Chapter 3). Questionnaires delivered information for more than one purpose and were as short as possible to minimise the risk of respondent fatigue.

Table 3 Overview of data collected, sample sizes and estimated percentage of the total study site populations, the thesis chapters in which each dataset was used.

Survey	Chapter	Sample size (estimated % of population)	Brief description
Hunter survey	3,4,6	n=205 hunters (>90%)	Face-to-face questionnaire administered to hunters, eliciting information about livelihood activities, hunting behaviour and details of most recent hunting trip in terms of numbers and species killed
Trader survey	3	n=50 traders (>60%)	Face-to-face questionnaire administered to bushmeat traders, eliciting information about livelihood activities, trading behaviour and details of most recent trading transaction
Household survey	4,5	Start of project: n=480 (>90%) End of project: n=524 (>90%)	Face-to-face questionnaire administered to households at the start and end of GolaMA project interventions, eliciting information about household demographics and involvement in livelihoods, including bushmeat hunting and trading. The bean method was implemented along with direct questions (see Chapter 5).
Village-based recording of hunters' catch	6	n=50 hunters (<25%)	Village-based assistants recorded details of hunting trips of participating hunters, over continuous monitoring periods of several weeks. Only trip duration and species killed were recorded.

The household survey provided livelihood descriptions of hunting and trading households versus non-hunting or trading households, assessed change in prevalence in hunting and trading at the start and end of the project, and explored the bean method as a tool for monitoring these behaviours. The hunter survey explored the livelihood and demographic profiles of hunters, economic incentives and disincentives, key aspects of hunter-trader relationships, the range of species killed and harvest estimates. The trader survey explored livelihood and demographic profiles of bushmeat traders, economic incentives and disincentives for traders, key aspects of hunter-trader relationships, and the range of species sold along different trade routes. Village-based recording of hunters' catch was designed to allow a comparative interpretation of harvest estimates from the hunter survey, and to trial this approach as a potential tool for community-based monitoring.

Sampling strategy

This research represents a case-study and the datasets are not intended to be representative of wider populations. Surveys were conducted across all villages, households, hunters and resident traders across a continuous geographic area, referred to as the study site, with sampling effort aiming to achieve universal sampling (i.e. 100% of the population). Chapter 6 gives more detailed discussion of potential sampling biases where universal sampling was not possible.

Villages included in the study

For the purposes of this study, I use the terms 'village' or 'town' interchangeably to refer to any permanent settlement with a town chief. Unless otherwise specified, any smaller semi-permanent 'camps' that fall under a village jurisdiction are considered part of the village. 'Settlement' is used to refer to any place inhabited by people on a permanent or semi-permanent basis (i.e. villages or camps). Clan 1 and clan 2 refer to the two clans that participated the GolaMA project (in chapter 5 these are referred to as Group 1 and Group 2 following a reviewers' recommendation).

All villages belonging to the two clans that participated in the GolaMA project were included in the study (Table 4). Only one village that belonged to clan 2 was not included in all surveys. This village initially chose not to participate in the GolaMA project, and subsequently joined after most data collection had already taken place. It was therefore only included as part of a small-scale study described in Chapter 5. The underlying reasons that clan 1 and clan 2 were selected to participate in the GolaMA project was because they had customary use of high conservation value forest adjacent to existing protected areas, and due to previously established relationships with the Society for the Conservation of Nature of Liberia, the organisation that implemented the GolaMA project.

In addition to the GolaMA project villages, four villages that did not participate in the GolaMA project were included in the study. The purpose of this inclusion was (1) to increase the sample sizes for datasets describing hunting and trading behaviour and (2) to enable interpretation of trends in hunting or trading prevalence with reference to a group which did not receive conservation project interventions. This study was not designed as an experimental impact evaluation of the GolaMA project so non-project villages are not intended to be 'control' villages but are used to allow qualitative comparisons with project households. Non-project villages were selected as the closest, geographically, to the GolaMA project villages, such that the survey covered all villages within a continuous geographic area. Additional selection criteria were that non-project villages should share forest boundaries and use the same road network as non-project villages to access major urban centres such as Monrovia. These criteria aimed to ensure non-project villages had similar resource-use and livelihood characteristics as non-project villages, would experience similar environmental and socio-political influences that were not related the GolaMA project, and that data collection would be achievable under the practical constraint of travel time and costs.

Table 4 Villages included in the study, and sample sizes based on complete sampling approach in which all households and all identified hunters and traders were included in the survey, unless otherwise stated.

settlement type	vehicle access in dry season[a]	number of households (2017 survey)	number of households (2019 survey)	hunter survey sample size	trader survey sample size	village-based offtake survey
Non-project clans						
village	car	14 (data not used)[b]	not surveyed	0	0	
village	motorbike	19	13	11	1	
village	car	48	64	11	8	
village	motorbike	76[c]	98	28	5	
Clan 1						
village	motorbike	12	8	17	4	
village	none	12	11	14	1	yes
village	motorbike	14	11	5	0	
village	none	17	18	3	not surveyed	
village	motorbike	20	19	11	1	yes
village	motorbike	20	19	11	2	
village	none	31	31	22	0	yes
village	motorbike	74	64	23	6	yes
Clan 2						
camp	none	1	0	10	not surveyed	
camp	car	2	3	0	not surveyed	
village	car	2	5	0	0	
village	car	4	5	3	0	
village	car	7	7	8	3	yes
village	car	10	10	5	0	
village	car	111	138	28	19	yes
village	car	not surveyed	69	not surveyed	not surveyed	

[a] *During the rainy season vehicle access was limited to motorbikes only, with only occasional accessibility for cars*
[b] *Data were not used as all households in the village were those of National Park Staff (see main text)*
[c] *Complete sampling of households was not achieved, estimated to be 60-70% of total*

Demographic variables recorded during the household survey indicated that socio-demographic variables (household sizes, literacy levels, tribal identities) were similar across non-project villages as project villages with only one outlier which was dropped from analyses. This village had been designated as the operational base for the Gola Forest National Park and consequently, all households belonged to park rangers whose livelihoods were not representative of those across other villages. The villages in the study included those on historic sites as well as villages with more recent origins as mining, logging or hunting camps (GolaMA, unpublished).

For some aspects of the study, a complete-sampling approach was not possible (Table 4). The trader survey was conducted in a sub-sample of ten villages: villages or camps were not included due to their small size and inaccessibility (two camps), because no traders were identified or encountered (six villages) or due to time constraints (two villages). The village-based offtake survey was conducted in six villages, largely due to practical constraints (see Chapter 6 for details).

Households, hunters and traders

The household survey encompassed all households in all villages, where a household was defined as a group of people who habitually 'eat from the same pot'. Hunters and traders were identified from a previous household survey conducted by GolaMA in 2015 (GolaMA, unpublished), from group meetings with hunters and chief hunters, from snowball sampling, and from the interviewers' own personal knowledge of the people in each village. Due to the personal familiarity of the research team with the study site it is considered likely that the overwhelming majority hunters and traders were identified with these methods. In particular, information from chief hunters is likely to be comprehensive as these individuals are responsible for allowing and regulating all hunting activity. Research technicians had a good relationship with chief hunters, who would have had little incentive to conceal identities of hunters. Thus, the team identified only eight hunters who either declined to participate or who could not be located during the study. The 205 hunter participants are estimated to represent over 95% of all hunters.

The sampling of traders may have been less comprehensive, and it is estimated that at least 60-70% of residents who sold bushmeat were identified. Research technicians who identified traders were themselves ex-bushmeat traders and so had direct access to the local trader network in clan 2, but were less familiar with traders in clan 1, and relied on traders self-identifying or being identified by others through snowball sampling. The survey methods excluded any people who were not resident in study site villages. As discussed in Chapter 3, a potentially significant proportion of bushmeat traders may have been non-residents and therefore were not included. Possible types of sampling bias associated with village-based monitoring and the hunter survey are discussed in detail in Chapter 6.

The research team

The data collection was carried out by a team of six research technicians who were all either locally born citizens or who had been living in the study site for several years prior to the study. The research technicians were therefore familiar with the study site and would have been known personally or by indirect family associations, to many of the participants. Research technicians were of the opinion that their existing relationships would be likely to promote more truthful reporting, as respondents would have felt that falsehoods would be easily detected.

This team included four research technicians who were employed by the GolaMA project (all male) to carry out a range of social and ecological surveys, and two additional research technicians (both female) who were recruited from the town in which the GolaMA project had a field office. The latter were not involved in the hunter survey interviews or village offtake study. Recruitment was based on people's literacy and availability. In some instances, data collection was assisted by additional GolaMA staff members. The hunter and trader focus group discussions were facilitated respectively by a male and female GolaMA staff, who each had experience in focus group facilitation and were also local residents in the study site. In two larger villages, data collection for the household survey in 2017 was assisted by a female GolaMA volunteer, who joined the team to ensure there was at least one female interviewer in each 2-person interviewer team.

All those involved in collecting data were trained in the methods and ethical procedures and underwent regular refresher training and de-briefing sessions. Research technicians were fluent in a range of local dialects, and interviewer-pairs were arranged to ensure that at least one member spoke the tribal languages of participants in each area. Where appropriate, interviewers translated the questionnaire for respondents and recorded answers in English. Many participants preferred to use English, but preferences for the indigenous languages of Mende or Gola were also common. Pre-survey training included exercises in which questionnaires were translated by research technicians, and back translated by someone who had not heard the original version.

Research technicians resided in a village where the GolaMA field office was located (this village was also part of the study) and travelled to other villages to conduct surveys in teams of two or more. Typically, research technicians would spend two or three days in each village, depending on the number and availability of survey participants, then proceed to the next-nearest village. The GolaMA research technicians were also responsible for collection of ecological survey data throughout the study period. This meant they regularly visited study villages and were able to collect some data for hunter and trader surveys opportunistically during such visits, i.e. whenever hunters or traders were encountered.

Timing of data collection

The timing of surveys was determined largely by practical considerations: most data collection took place during the dry season when villages were easier to access (Oct-July), was fit around ecological surveys being carried out concurrently by the research team and avoided peak agricultural periods such as harvests (Fig 2). I was in the field throughout most of the data collection period, but was in the UK in Sep 2016, from Sep to Aug 2018, and after July 2019.

Ethics

Free, prior informed consent was obtained from all study participants, and from the local authorities at the level of villages and clans. Introductory public meetings were held in all study villages prior to data collection. Meetings were attended by village leaders, who included the women, youth and hunter representatives, and were facilitated by GolaMA project staff. At these meetings GolaMA staff explained the purpose of GolaMA project (this had also been described in separate meetings previously), and the overall aim of the research. The latter was described as being to learn about peoples' livelihoods, wildlife use and specifically the hunting and trading of bushmeat. It was explained that anyone would be free to take part, or to choose not to participate, and that this decision would have no consequences for the individuals or for the communities as a whole. It was emphasised that people's free choice to participate in the research would not affect any of the GolaMA project activities, or their eligibility to be involved in those. People at the meetings were informed that all data would be confidential; that results would be presented in reports that could be read by government bodies and the wider public; that participants could withdraw consent to participate at any point by telling any researcher or GolaMA staff member; and that survey results would be shared with participants in meetings after the study's completion. It was explained that participants would not receive any payment for participation. All participants in questionnaire surveys were similarly provided with this information. Results of the household, hunter and trader survey data collected at the start of the project were shared with community members by GolaMA staff in April 2017 during visits to villages. A printout summarising the main findings at the clan level was used by staff as a basis to discuss the results at a meeting, and this was publicly posted in each village. Findings were discussed in more detail in separate meetings of key stakeholders, including the clan chiefs and GolaMA project managers in 2019 (GolaMA in prep).

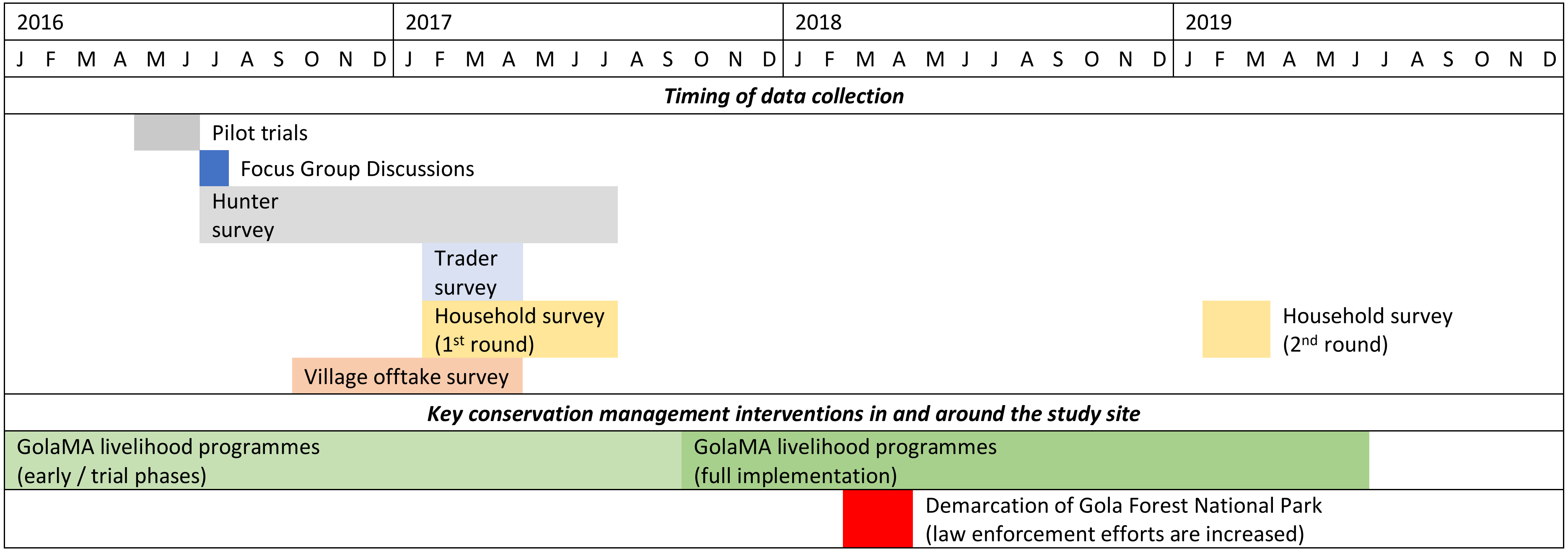

Figure 2. Timing of data collection and of conservation interventions at the study site. GolaMA livelihood programmes consisted of training and equipment to support income from bee-keeping, perennial crop agriculture (peanuts, beans), swamp farming techniques, cocoa farming. A small loans scheme and an adult literacy evening class were also provided. In the early / trial phase, schemes were rolled out on a smaller scale than in the full implementation stages, being offered primarily only to selected groups of participants. For example, during trial phases bee-keeping groups were limited to approximately 15 persons; perennial crop agriculture was offered to specific village groups; the small loans scheme was only available to womens' loans groups and maximum loans were initially limited; cocoa training was only available to those with cocoa farms and evening literacy classes were not yet offered. In the full implementation phases, bee-keeping was expanded as carpenters were trained to produce bee-hives locally and these were bought by the project for bee-keepers, agricultural demonstration plots were established in all villages and training was offered to more participants, small loans schemes were available to any type of loans group and maximum loans were higher, cocoa farmer training was offered to anyone and some participants were trained as farmer-teachers, and adult literacy classes were provided in larger villages.

Trial of survey formats

Informal conversations with hunters and non-hunters during the 18 months prior to the start of the research, indicated that people felt comfortable discussing all aspects of their own and others' hunting and bushmeat trading activities. This impression was supported by a household survey conducted by the GolaMA project in 2015 in which people readily identified themselves as hunters or bushmeat traders and shared information about these activities (GolaMA, unpublished). Therefore, it was considered appropriate to use face-to-face interviews to obtain information from hunters and traders.

While people were evidently comfortable discussing hunting and bushmeat trading, it was assumed that responses might be susceptible to some level of social desirability bias given that most hunting and trading practices were illegal. It was anticipated that these activities would be more susceptivle to mis-reporting following GolaMA project interventions, for example, once people had signed agreements with the project stating they would refrain from hunting or trading as a condition of participation in livelihood support programmes. Therefore, in order to measure prevalence of hunting and trading at the end of the project, it was considered appropriate to use specialised methods that aim to minimise misreporting of sensitive behaviour by preserving respondents' anonymity. A short pilot trial was conducted to compare different approaches in terms of how straightforward they were to implement and how they would be received by respondents.

A trial of the randomised response technique (RRT) and unmatched count technique (UCT) was conducted as part of the hunter survey (described above). These techniques were used to explore killing of high profile protected species: a topic that was potentially more sensitive than other hunting behaviours, since some hunters were aware of its illegality, and GolaMA activities included raising awareness of the protected species laws. The RRT questions were administered at the end of the hunter survey questionnaire to the first 108 hunters who were approached for the survey, covering 13 villages. A UCT question was also administered to 95 hunters from this group. For the remaining surveys, administered to 142 hunters, questions about killing protected species were asked directly. Because some hunters were interviewed on more than one ocassion, 45 hunters responded both to RRT/UCT and subsequently to the direct questions.

The RRT was used to ask hunters four questions about whether, in the previous 10 years, they had killed any of four species. Chimpanzee (*Pan troglodytes*), Forest Elephant (*Loxodonta cyclotis*), Pygmy Hippopotamus (*Choeropsis liberiensis*) and Bongo (*Tragelaphus eurycerus*) were chosen as species that were high priorities for conservation efforts with protected status that was relatively widely publicised in Liberia.

The RRT method was implemented using a bag with 6 coloured balls: 2 red, 2 blue, 2 white. Respondents were instructed to draw 2 balls from the bag, without revealing their colours to the interviewer, and to answer 'yes' to the question if they had 2 red balls, 'no' if they had 2 white balls, or truthfully for any other colour combination. Dummy questions were used to demonstrate the answering format. Estimates of true prevalence were calculated as proportion of observed 'yes' responses minus the probability of a 'forced' yes (i.e. 1/9), divided by the probability of a truthful answer (i.e. 7/9) (Table 5; Nuno and St John, 2015).

The UCT was applied to ask about killing of chimpanzees (*Pan trogolodytes verus*) in the previous 10 years. Chimpanzees were selected since this species was thought to be killed more frequently than the others. Respondents were shown a sheet with pictures of four other bushmeat species, two of which were known to be commonly killed (a duiker and porcupine) and two of which were considered to be rarely killed (leopard and crocodile). Half of the picture-sheets also showed a chimpanzee. Respondents were instructed to state how many of the animals shown they had killed in the previous 10 years. Treatment was randomised between respondents, such that n=38 hunters were shown the version that included a chimpanzee and n=43 the version without. Estimated prevalence was calculated as the difference in the means of the two groups (Table 5).

Table 5. Reported prevalence of killing high-profile protected species in the previous 10 years by hunters, obtained from a trial implementation of the randomised response technique, unmatched count technique and direct questions.

In the last 10 years, have you...	Randomised Response Technique (n=108)	Direct question (n=142)	Unmatched Count Technique (n=81)
killed any chimpanzee	56%	27%	40%
killed any pygmy hippopotamus	2%	11%	-
killed any bongo	19%	19%	-
killed any elephants	0%	0.1%	-

Correlations between responses given to UCT and the RRT question about killing of chimpanzees were explored using a 'quasi-poisson' generalised linear model with poisson errors and a dispersion parameter to allow for over-dispersion. The UCT response was modelled as a function of the RRT response and the treatment group, including interaction term. Results indicated that estimates of chimpanzee killing based on UCT did not correlate with RRT responses (estimated RRT effect =0.02, estimate S.E. = 0.05, p=0.6, n=81).

In the direct questioning format, hunters were asked how many of each of the species they had killed in the previous 10 years, rather than whether or not they had done so. This phrasing was used as it was considered more permissive: i.e. it implies the interviewer expects hunters to have killed at least one of each species. Eliciting numeric answers also provided information about frequency which was lacking from RRT/UCT method. Comparison between the direct responses and the RRT and UCT methods are shown in Table 5. For chimpanzee killing, a smaller proportion of respondents reported the behaviour directly compared to RRT, but the reverse was true for pygmy hippopotamus and elephant. The difference in chimpanzee prevalence estimates could indicate that this activity was under-reported and potentially sensitive. However, this interpretation may not hold for several reasons. The sample of hunters who responded to the RRT format may not be comparable to the direct question sample. This is the RRT was administered adhoc to the first hunters to be identified and surveyed, while the direct questions were administered to hunters who were identified later in the study. The most readily identified hunters would likely be those for whom hunting forms a main component of their social identity, who are also more likely to own guns, have been hunting for a long time, and have had opportunities to kill chimpanzees. It was also noted that several respondents (n=11, 8%) in the direct question sample volunteered the information that they had killed chimpanzees in the past, but it had been longer than 10 years ago. The RRT does not allow for this nuanced response, so hunters who had killed the species, but over 10 years ago, may have responded with ‘yes’.

Feedback from interviewers indicated that respondents found the both the RRT and UCT methods confusing and both were time-consuming to explain and demonstrate. The UCT format of giving a numeric response without identifying which species had been killed, was particularly counter-intuitive for respondents. Throughout the study, interviewers had the impression that most hunters were comfortable reporting answers openly, suggesting that the level of sensitivity was not high enough to warrant the time needed to implement these methods. Nevertheless, both methods could likely have been improved: for instance with thorough pre-testing of items for the UCT (Hinsley *et al.* 2017).

The bean method was seen as a potentially more straightforward approach than RRT or UCT (Lau *et al.* 2013; Chapter 5). To explore this assumption, randomly chosen individuals from a nearby non-study village, were shown the RRT approach described above and the bean method (see Chapter 5). Interviewers demonstrated the methods with examples of sensitive questions (e.g. have you ever stolen something) and elicited answers to bushmeat hunting and trading questions using both methods. Respondents were then asked which methods they had found easy or difficult to understand and which they felt best ensured their answers could not be determined by the interviewer, and the reasons for their answers. Respondents unanimously reported that the bean method was easiest to understand, and approximately 50% considered it the more ‘secretive’ method (the trial was conducted with approximately 20 respondents, but unfortunately the data have not been kept so exact numbers cannot be presented). Feedback from interviewers indicated the bean method was straightforward and fast to administer. Based on this trial, the bean method was considered to be an appropriate technique that could be a useful tool to measure potentially sensitive behaviours.

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Chapter 3. Incentives and social relationships of hunters and traders in a Liberian bushmeat system

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Incentives and social relationships of hunters and traders in a Liberian bushmeat system

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A B S T R A C T

Hunting provides livelihoods and food security for a large number of people across the tropics but endangers wildlife populations. Effective management requires understanding both social and economic dynamics of local bushmeat systems, yet social elements such as relationships between actors are often overlooked. We provide the first detailed description of a rural hunting system in Liberia, from interviews with 205 hunters and 50 traders in the Gola Forest. We found bushmeat contributed substantially to local livelihoods and earnings from hunting and trading were high relative to local alternatives (median US$120 and $US262/month, hunters and traders respectively). Most of hunters' catch was sold to traders (85% of harvested biomass) and subsequently transported to urban markets (65% of all harvested biomass). Local consumption accounted for 27% of total harvest. Financial risks from meat confiscation were primarily born by traders, many of whom were women, and 60% perceived this as a motivation to reduce trading. By contrast, the most commonly stated motivation to reduce hunting was the time demanded by alternative activities such as farming. This discrepancy implies that livelihood support initiatives and law enforcement tools may play distinct roles across groups. Relationships between hunters and traders were complex and involved a variety of credit arrangements. Interpersonal trust played an important role, with mistrust of hunters being cited by 12% of traders as the principle barrier for profiting from bushmeat trade. Our findings provide context for designing conservation strategies and suggest that underlying social processes deserve closer attention in bushmeat research.

1. Introduction

Over-harvesting of wildlife for human consumption is a problem for wildlife populations and the humans who depend on them. Hunting provides a valuable source of income and food for a large number of people living around tropical forests (Cawthorn and Hoffman, 2015) but is unsustainable at current levels (Benítez-López et al., 2017) and puts species at risk of extinction (Milner-Gulland et al., 2002; Oates et al., 2010). A good understanding of both the social and ecological elements of hunting systems is needed to develop effective tools to address this problem (Dorward, 2014; Milner-Gulland, 2012). Information about the contribution of bushmeat to local livelihoods, actors in the supply chain, their motivations and their interpersonal relationships provides valuable context for designing hunting reduction programmes. Closer attention to social features in this system could reveal barriers and incentives for behaviour change that are often overlooked by conservationists.

The role of bushmeat in people's livelihoods varies across sites; in many cases it provides a cheap source of protein as well as income (Foerster et al., 2012; Golden et al., 2014; Schulte-Herbrüggen et al., 2013). The commercial supply chain typically involves multiple actors: traders or intermediaries who transport meat to markets, market-sellers, restaurateurs and consumers (Cowlishaw et al., 2005; Nielsen et al., 2016). Commercial hunting can be financially rewarding relative to local income alternatives (e.g. Coad et al., 2010; Nielsen and Meilby, 2015), and bushmeat may provide an economic safety net (Enuoh and Bisong, 2014), help to smooth income across lean seasons (Schulte-Herbrüggen et al., 2013), or generate social capital (De Merode et al.,

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2004; Van Vliet et al., 2015). The economic value of bushmeat presents a challenge of motivating behaviour change in individuals who have strong financial incentives to continue hunting, while ensuring that conservation efforts do not negatively impact vulnerable people (Roe, 2008).

Conservation strategies often aim to influence economic drivers of hunting. Regulatory interventions introduce financial risks such as fines for non-compliance with hunting restrictions (Tranquilli et al., 2014), while incentive-based approaches aim to alleviate economic dependence on wildlife resources (Niesten et al., 2010; Roe et al., 2015; Wright et al., 2016) or financially motivate behaviour change (Ferraro and Kiss, 2002). Projects often promote environmentally sustainable income sources (Roe et al., 2015), such as bee-keeping, while tools from social development, such as micro-credit schemes, are intended to improve social outcomes of conservation projects (Kaaya and Chapman, 2017). Aiming to change behaviour, cultural norms, and decision-making infrastructure, such interventions have the potential to alter social dynamics of local systems, which in turn may influence how natural resources are used (Miller et al., 2012). However, such feedback mechanisms are poorly understood (Larrosa et al., 2016), and there is little empirical guidance for conservation managers when it comes to designing interventions (Wicander and Coad, 2015).

The social context in which bushmeat hunting occurs may be central to developing effective conservation strategies. Social factors have a strong influence on behavioural decisions (Farrow et al., 2017; Morsello et al., 2015) and are inherent in bushmeat systems which typically involve multiple stakeholders. Yet components such as inter-personal relationships remain largely overlooked in conservation research (Robards et al., 2011). The handful of studies examining social features of bushmeat systems provide valuable insights (Coad et al., 2013; Cowlishaw et al., 2005; Nielsen et al., 2016; Nielsen and Meilby, 2015; Van Vliet et al., 2015, 2014). For instance, Nielsen et al. (2016) describe an illegal bushmeat trading system built upon long-term relationships between hunters, traders and consumers, in which access to a trusted network created an entry barrier for hunting. The contrasting lack of inter-personal relationships with law-enforcers in this system may have contributed to violent rent-seeking behaviour. In the Amazon basin, Van Vliet et al. (2015) revealed substantial non-commercial flows of bushmeat to urban centres via close friendships and family ties, with sharing of meat linked to cultural identity and norms of reciprocity. Commercial trade meanwhile, was associated with a distinct socio-economic group who consumed meat as a luxury item. Framing bushmeat as a problem of common resource governance could also generate helpful insights (Smith et al., 2019) and adds prominence to factors such as trust and cooperation, which are often overlooked. Social environments can change rapidly in response to political, economic or technological shifts, which can have important consequences for resource use (Nackoney et al., 2014; Walters et al., 2015). A better understanding of the social context in which hunting systems operate provides a basis for designing appropriate conservation interventions and advances our understanding of behaviour change tools more generally.

Liberia is under-represented in the bushmeat literature (Taylor et al., 2015) despite high levels of bushmeat consumption and globally threatened wildlife populations. Anstey (1991) estimated that bushmeat provided 75% of the country's meat, generating $24 million annually. A survey conducted after the civil conflict suggested that 80% of Monrovia's population consumed bushmeat, and found evidence that Liberia supplied a global trade with international exports from the capital (CEEB, 2004). More recently, a nationwide survey confirmed that hunting and consumption remains widespread (Junker et al., 2015b), although consumption decreased somewhat among wealthier households during the Ebola crisis in 2014–15 (Ordaz-Németh et al., 2017). This high level of demand coincides with an area of high conservation priority: Liberia retains the largest portion of forest in the Upper Guinea biodiversity hotspot (Mittermeier et al., 2003) and consequently harbours populations which are critical to the long-term survival of species such as western chimpanzee (*Pan troglodytes verus*) (Kühl et al., 2017) and pygmy hippopotamus (*Choeropsis liberiensis*) (Hillers et al., 2016). Over-hunting remains one of the principle threats for wildlife in Liberia and has resulted in local extirpation of large-bodied species (Junker et al., 2015a; Tweh et al., 2014). Financial incentives for hunters are likely to be high. The only existing study of hunters' incomes found average returns exceeded US$1500/month for hunters in commercial camps near Sapo National Park (Greengrass, 2016). The economic role of bushmeat in rural livelihoods outside of professional hunting camps is largely undescribed and a better understanding of the economic and social structure of bushmeat systems in Liberia is needed to support conservation efforts in the region.

We aim to describe the structure of a bushmeat trading system in Liberia from a social, economic and livelihood perspective. We use a case-study from the Gola Forest to examine livelihood dependence, motivations and inter-personal relationships between hunters and traders.

2. Methods

2.1. Study site

The study was conducted in Kongba District, West Liberia, at the site of the Gola Management Agreement (GolaMA) conservation project (www.golarainforest.org/gola-liberia). The area covers approximately 400 km^2 of lowland rainforest, bordering Sierra Leone and connecting two protected areas that together form a transboundary “Peace Park”, the Gola Forest National Park in Liberia, and the Gola Rainforest National Park in Sierra Leone. In Liberia, national laws prohibit hunting within protected areas and of certain species irrespective of where they are caught.

GolaMA is a community-based conservation management program that began in 2014, implemented by the Society for Conservation of Nature of Liberia and the Royal Society for the Protection of Birds. At the time of data collection, GolaMA's work focused on supporting communities to apply for legal forest management rights and introducing small-scale livelihood support projects such as agricultural training and bee-keeping initiatives. As in much of rural West Africa, subsistence agriculture forms a major component of local livelihood strategies, along with commercial crops including oil-palm and cocoa. The study area is also notable for diamond and gold deposits, and small-scale mining is a locally significant activity. The site has relatively low population density and high quality of forest resources (Hillers, 2013). Previous work shows hunting is practiced by about 40% of households, and hunters use shotguns (39%), snares (24%) or both (37%) (Jones et al., 2009). A more detailed analysis of the demographic, livelihood and behavioural profiles of hunters in the site is presented by Jones et al. (2009).

Familiarity with the study site was obtained by SJ over a period of two years, and AF and ZN are local to the region. Data were collected by researchers who were local residents and where possible, female researchers conducted interviews with traders, many of whom were women. Interviews were conducted in English or local dialects based on respondents' preference. Preliminary results of a study using specialised techniques for asking sensitive questions (Lau et al., 2011; Nuno and St John, 2014) confirmed that hunters and traders were comfortable openly discussing hunting and bushmeat trading, and other potentially

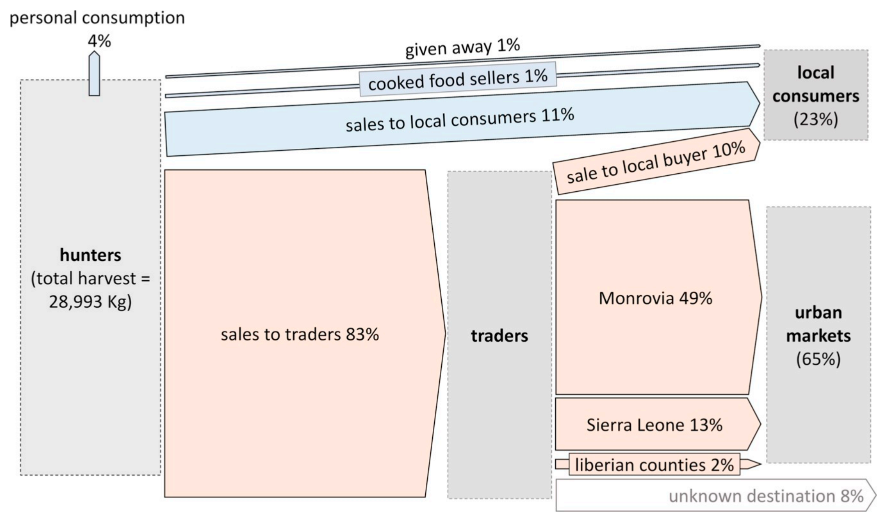

Fig. 1. Destination of wildlife harvest based on hunters' reports (n = 253 hunting trips). All values shown are percentages of original total harvested biomass and width of arrows is proportional to volume in kg.

sensitive topics such as income sources (Jones et al., 2009). Ethical approval was given by Royal Holloway University of London Ethics Committee.

2.2. Hunters

Interviews were conducted between July 2016–July 2017 at all villages (n = 15) and two semi-permanent camps in the study site. Hunters were identified through meetings coordinated by chief hunters at each village, a household survey and snowball sampling. If hunters were not available for interview, researchers returned a minimum of three times before excluding them from the study. Hunters were asked general questions about their hunting activity and to provide details of their most recent hunting trip including species killed, the sale or consumption of carcasses, and prices received. To determine trade routes, hunters were asked the final destination of meat sold to traders. Hunters that could be re-found were interviewed multiple times giving information for up to three separate hunting trips. Liberian dollars were converted to US$ using the local exchange rate in July 2017 (LD100:US $1). Catch was converted to raw biomass based on values in Kingdon, 2015 and Jones et al., 2009. Additional information relating to hunters' socio-demographic profiles were obtained during the hunter interviews and are presented in separate study (Jones et al., 2009).

The perceived contribution of hunting to personal income relative to other activities was assessed by inviting participants to share a pile of 20 beans among the income generating activities they had profited from in the past year. This was repeated for the past months' income share. Participants were also asked to estimate the income each activity generated over an average month and the previous year. Sample sizes are reported for questions about contribution of hunting to personal income that were added part way through the study.

2.3. Traders

Interviews were conducted with all traders identified in ten villages in the study site. We defined 'trader' as anyone who bought meat from one or more hunters and re-sold it. Five villages and two semi-permanent camps within the study site were not included due to their small size and inaccessibility (two camps), because no traders were identified or encountered (three villages) or due to time constraints (two villages). Traders were identified in the same way as hunters. Respondents were asked about trading behaviour and to provide details of their most recent transaction including species bought and sold. Contribution of trading to personal income was assessed with the bean-sharing method described above. Specific information regarding trade routes and customers was not requested as this could have led to targeted law enforcement efforts at road blocks. For this reason, we do not distinguish traders who acted as intermediaries by transporting meat for resale to market sellers or restaurateurs, from end-of-chain suppliers selling directly to consumers. However, it is our understanding that sales of meat transported to urban centres were typically made to market sellers, while local sales were to consumers.

2.4. Focus group discussions

Focus group discussions were conducted to generate broader understanding of hunting and trade by capturing personal perspectives of actors (Nyumba et al., 2018). One discussion per group was conducted with hunters in six villages and traders in one village. Groups comprised six to nine participants, recruitment was opportunistic based on availability of individuals encountered by the facilitator. Hunter discussions were mediated by a facilitator and recorded with a sound recorder. The trader focus group was restricted to female participants and mediated by a female facilitator with data recorded by a female note-taker. Topics discussed were: the challenges and benefits of bushmeat hunting or trade and the role of bushmeat in relation to other livelihood activities.

3. Results

3.1. Socio-economic aspects of the hunting system

3.1.1. Hunters

A total of 213 hunters were identified, of which 205 participated in the study. Of these, 48 hunters were interviewed on more than one occasion giving a sample of 253 hunting trips, totalling 999 hunting days. Hunter catch totalled 2088 carcasses from 30 species: 27

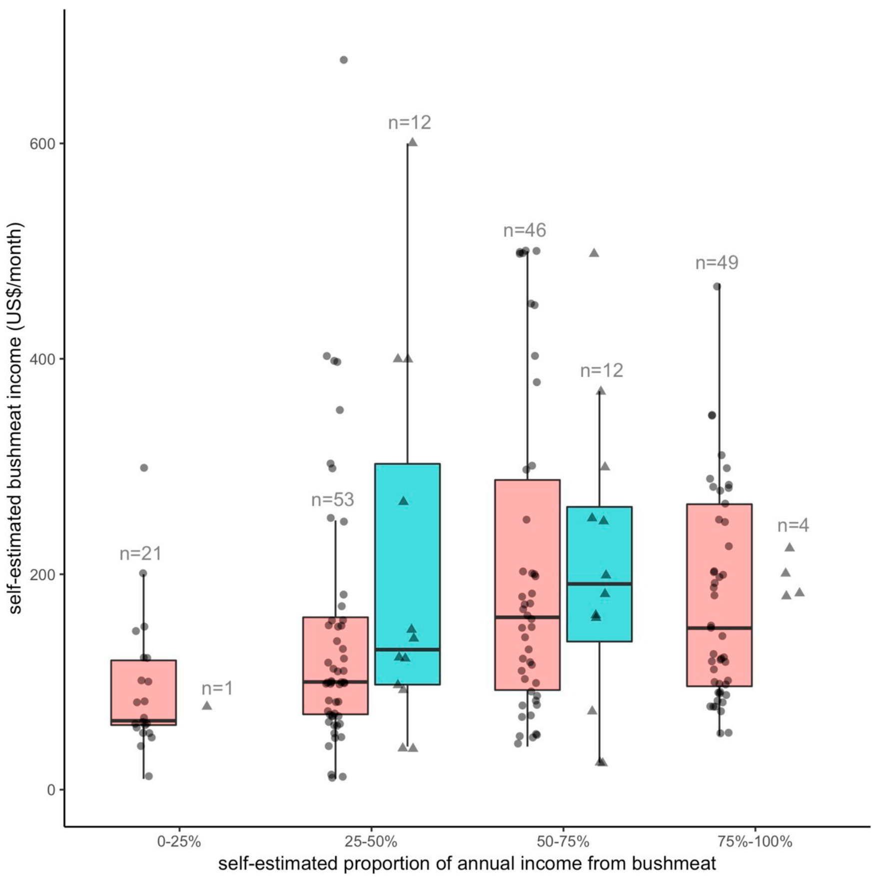

Fig. 2. Bushmeat income estimated by hunters (red, circles, $n = 169$) and traders (blue, triangles, $n = 29$), grouped according to perceived proportion of annual income from bushmeat. Four high hunter estimates are omitted for clarity, from income proportion categories 25–50% ($800/month), 50–75% ($800 and $900/month) and 75–100% ($2800/month). Boxes indicate median and 25%–75% quartile range for cases with at least 10 values, whiskers extend to 1.5xIQR beyond boxes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

mammals, 2 birds and 1 reptile (Appendix A, Table A.1). Total harvested biomass was approximately 29 metric tonnes.

Hunters sold the majority of catch to traders (Fig. 1). Sales to traders for transport to urban markets included 24 species and accounted for most of the carcasses and harvested biomass. Local consumption included 23 species. Seven large and infrequently caught species were only recorded as sold to urban markets (Appendix A, Table A.1), including western chimpanzee (*Pan troglodytes verus*, $n = 5$) and Jentink's duiker (*Cephalophus jentinki*, $n = 9$). Six mainly small-bodied species were only consumed locally (Appendix A, Table A.1), including white-breasted guineafowl (*Agelastes meleagrides*, $n = 16$) and greater cane-rat (*Thryonomys swinderianus*, $n = 33$). Carcasses destined for urban markets were first dried by the hunters at the time of capture or by traders after purchase. Fresh carcasses were sold in local villages door-to-door by hunters and traders, either whole or butchered (pers. obs). Long journey times prevented transport of fresh carcasses to urban markets. The most common destination for meat was Liberia's capital, Monrovia, followed by markets in Sierra Leone and neighbouring Liberian counties. Hunters did not know the destination of 8% of carcasses (8% of biomass). Mean sale price reported by hunters was US$ 0.82 kg^{-1} raw weight (SD = 0.37, range = 0.05–2.78, $n = 765$ transactions) and did not vary substantially by species (Appendix B, Figs. B.1, B.2). Mean sale price of carcasses destined for urban consumers was slightly higher than local consumers (US$ 0.86 kg^{-1} SD = 0.38, $n = 495$, compared to US $0.74 kg^{-1}, SD = 0.31, $n = 270$). Mean price that traders reported paying hunters was slightly lower than the price hunters reported receiving from traders (US$0.70 kg^{-1}, SD = 0.18, $n = 114$ transactions, compared to US$0.83 kg^{-1}, SD = 0.37, $n = 622$ transactions).

Hunting was the principle income source for most hunters (74%) followed by farming (19%). Hunters estimated that bushmeat provided 62% of their income during the previous month on average (range = 5–100%) and 55% of income for the past year (range = 5–100%; Fig. 2). Self-estimated monthly earnings from hunting ranged from $10–$900 (median = 120, IQR = 80–200, $n = 174$; we exclude an unreasonably large estimate of $2800). Hunters' average gross revenue per day during their most recent hunting trip was US$22 (SD = 19, range = 0–110; median = $16, IQR = 8–30).

3.1.2. Traders

A total of 51 traders were identified and 50 participated in the study. Focus groups revealed that transient, non-resident traders operated in the area but were not identified during this study. We expect the trader sample therefore to represent only a portion of trading activity, with possible bias toward residents with a high social profile. Most (80%) of traders were women and 38% came from the same village. The majority (80%) had emigrated from elsewhere in Liberia between one and 25 years previously (median = 7, IQR = 3–12). Among traders interviewed, 57% reported to sell at least some of their meat locally, 90% sold meat to Monrovia, 4% to Sierra Leone and 8% to the neighbouring Liberian county of Lofa. The majority (86%) used cars to transport dried meat, and fees paid to commercial car operators ranged from US$1.2–6.8 per carcass (mean = US$3.8, SD = 1.5).

Bushmeat trading was cited as the principle livelihood by the

Table 1
Reasons given by hunters (n = 92) and traders (n = 45) who stated during interviews they had reduced their effort in bushmeat activities in the previous year compared to the preceding one. Values are the percentage and number of total respondents giving each reason.

Reasons for reduction in hunting/trading effort in the previous year (*example statements*)	Hunters	Traders
Government restrictions and law enforcement	21%	60%
"*the arresting of meat on the road*"	(19)	(27)
"*because they're taking the meat from us*"		
Replacement with a different income generating activity	32%	(0)
"*farming is now my focus point*"	(29)	
"*because I went to gold mining*"		
"*busy with farming*"		
"*I have more activities this year than hunting*"		
Fewer animals	21%	16%
"*the animals are not as many compared to last year*"	(19)	(8)
"*I travel far distance in hunting and get less animals*"		
Awareness about conservation, GolaMA project activities	13%	7%
"*conservation message*"	(12)	(3)
"*golama say no hunting*"		
Personal/health issues	8%	4%
	(7)	(2)
Financial barriers, lack of gun	5%	2%
"*bullets are expensive*"	(5)	(1)
"*someone go with my gun*"		
Limited by supply from hunters, or support from traders	1%	4%
"*more hunters leaving their hunting tent*"	(1)	(2)
"*because the hunters are not doing any hunting*"		
"*I did more hunting [before] because of my partner help*"		
Transportation issues	(0)	2%
"*poor road condition*"		(1)

majority (78%) of traders, followed by trading in other goods (14%) such as foodstuffs, kitchenware or clothing. A majority of traders (73%) also traded non-bushmeat goods. Traders estimated that bushmeat provided 53% of their income during the previous month on average (range = 0–100%) and 49% of income for the past year (range = 20–100%; Fig. 2). Self-estimated maximum monthly earnings ranged from US$15–$1600 (median = 200, IQR = 88–320) and minimum monthly earnings ranged from US$10–$1200 (median = 120, IQR = 55–155). Estimates of typical monthly profits were from US$3–$600 (median = 120, IQR = 59–220; n = 42, Fig. 2). Traders sold carcasses for an average of 1.9 times the price they paid hunters (SD = 0.4; range = 0.2–3.4). Mean re-sale prices reported by traders was US$1.30 kg^{-1} (SD = 0.54, n = 119 sales). Traders often bought multiple carcasses over a period of time which were transported or sold together in a single 'transaction'. Traders conducted an average of 2.7 transactions per month (SD = 2.1, range = 0.5–15), selling an average of 17.9 carcasses per typical transaction (SD = 13.90, range = 1–60). Mean expenses were US$86 per transaction (median = $60, range = $2–360). Average net profit was US$87 per transaction (median = $50, range = $1–440, SD = 101.6). However, a lower profit estimate of $24 (range = $1–$243) was obtained when traders were asked to recall details of species bought and sold, rather than report their overall expenses and returns. Similarly, the mean number of carcasses recalled from the most recent transaction was substantially lower than the value reported as 'typical' (mean = 8.1, SD = 7.0, range = 1–38).

3.2. Motivations and disincentives

Confiscation of bushmeat by authorities was perceived as a considerable financial risk among both hunters and traders and was regularly mentioned in focus group discussions. Among hunters asked (n = 136), 45% had previously had meat confiscated at least once, and 25% had had their meat confiscated more than once. Median value of confiscated meat was US$390 (range = US$50 to 2500, IQR = 225–642, n = 58). Among traders, 71% had had their meat confiscated at least once, and 58% on more than one occasion. Median value of confiscated meat was $320 (range = US$22 to 1804, n = 36).

The majority of hunters and traders reported doing less hunting or trade in the previous year than the preceding one (70% of hunters, 90% of traders; Table 1). The most common reason given by hunters was involvement in other activities such as farming, followed by enforcement of government restrictions and fewer animals. Most traders cited government restrictions, followed by reduction in animal populations (Table 1). Traders asked about factors that made meat trade challenging most frequently cited confiscation of meat at roadblocks (31 respondents, 62%; Appendix C, Table C.1), followed by the costs of transportation (6 respondents, 12%) and issues relating to mistrust with hunters such as paying hunters in advance without receiving meat in return (6 respondents, 12%).

Trader focus group discussion indicated transportation costs were a key factor perceived to limit bushmeat profitability and that these were exacerbated both by poorly maintained roads and a local monopoly of commercial vehicle operators. Participants noted that transportation barriers were reduced when companies (such as logging or mining companies) were active in the area. However, high costs of transporting goods simultaneously created a motivation for increased involvement in bushmeat trade. This was because traders taking bushmeat to urban centres had the opportunity to purchase goods with cash from bushmeat sales. Profit margins for non-bushmeat goods were reportedly low and more severely impacted by transport prices, motivating traders to compensate by increasing bushmeat sales to make up the shortfall. Purchase of goods and gun cartridges in urban markets using cash from bushmeat sales may have helped offset the cost of return journeys. Traders also minimised transport fares by sending meat via trusted third parties, such as vehicle operators, to known urban buyers without travelling themselves. Traders rarely transported non-bushmeat goods, such as non-timber forest products or agricultural produce, to urban centres due prohibitively expensive fares.

3.3. Hunter trader relations

Partnerships between hunters and traders were frequently mentioned during focus group discussions, and 28% of hunters had a specific "business partner". Two thirds of partnerships were with female traders, and 13% were with spouses or family members. Mean duration of partnerships was 2.7 years (SD = 3.4, n = 39). Typically, trading partners offered hunters financial support of some kind, to be repaid with a regular supply of meat. In 68% of such arrangements, trading partners provided gun cartridges, but exchanges also included food (42%), cash advances (11%), wire for snares (8%) or other items such as batteries (5%). The most frequent agreement was that hunters provide the equivalent of two medium-sized duiker carcasses (totalling 30–40 kg in raw weight) in exchange for a box of 25 gun cartridges (39% of agreements). Other common arrangements were that hunters provide the trader with a minimum number of carcasses per month (31% of agreements), or that hunters agree to exclusively sell their catch to the partner (8%). Agreements were similar for partnerships with male or female traders. Informal discussions indicated that relationships between hunters and traders were complex and varied. For instance, traders who owned small businesses offered hunters credit for goods such as food, cigarettes and alcohol, to be repaid with meat from their next hunting trip. Reports suggested some hunters followed a predictable pattern of generating debt in the village, followed by hunting trips to repay creditors – a cycle which made it hard to generate capital to pursue alternative income sources. Traders who were not local residents were reported to travel into the study site from urban centres with goods such as clothing to exchange for meat from hunters. A popular narrative was of hunters cheating traders who provided gun cartridges and food for hunting trips, by secretly selling meat in the forest and claiming not to have caught anything. Romantic relationships between hunters and traders of different gender were also alluded to as somewhat common. It was noted that hunters were able to help girlfriends or wives by providing them with bushmeat to sell, as well as off-cuts to eat and direct financial support. Informal conversations with hunters, traders and other local citizens suggested that a majority of traders selling meat in Monrovia had close ties with a single trusted buyer. This buyer could be relied upon to safeguard traders' money until it was needed, much like a bank or savings group, and offered credit or financial support in times of crisis to both hunters and traders. Taken together, such anecdotes implied that interpersonal relationships were important components of the hunting-trading system.

4. Discussion

This study provides the first detailed description of the social and economic structure of a rural Liberian bushmeat system. The results reveal substantial livelihood dependence on bushmeat with high financial incentives for both hunters and traders. Bushmeat demand came from both local and urban markets with a high proportion of meat destined for Monrovia. Hunters and traders each had different motivations to reduce effort, suggesting that conservation programmes need to operate across multiple groups in order to be effective. Such programmes also need to take into account the complex social contexts within which hunting and trade operate. We found evidence that interpersonal relationships between hunters and traders, characterised by credit arrangements based on mutual trust, were influential components of the system, yet these are often overlooked.

We found bushmeat was a significant cash-generating component of local livelihoods: more than half of hunters and traders estimated that bushmeat provided at least 50% of annual income, and almost three quarters of hunters considered hunting their principle profession. This reinforces the need for livelihood support tools to be integrated into conservation strategies. Financial incentives of individuals were also considerable. Typical earnings of hunters and traders were variable and generally high relative to local opportunities; a pattern that has been observed at other sites across Africa (Coad et al., 2010; Grande-Vega et al., 2013; Olupot and Plumptre, 2009). Hunters reported earning \$120/month, whereas monthly earnings for local teachers range from \$40–\$100, unskilled company employees (e.g. security guards) receive \$70–\$80, and small-holder cocoa farmers can generate approximately \$300/year on 3 ha (S. Kamara, personal communication). Standard rates for manual labour are \$5/day (pers. obs) while hunters were able to earn \$10–\$20/day. Traders' incomes were slightly higher, with average self-estimated monthly earnings between \$120–\$260. Self-reported incomes should be interpreted cautiously since they are prone to error and reporting bias (Krumpal, 2013; Mathiowetz et al., 2002). Nevertheless, values from this study fall within the range recorded for similar settings (e.g. Coad et al., 2010; Kümpel et al., 2009; De Merode et al., 2004; Grande-Vega et al., 2013) and provide a benchmark to inform conservation efforts.

Bushmeat incomes were an order of magnitude lower than those previously recorded by Greengrass (2016) at commercial camps near Liberia's Sapo National Park. This is unsurprising as our study describes a village hunting system, rather than a camp of professional hunters. However, the upper range of estimates in our study exceeded \$1000/month, suggesting that even in a village context, a minority of hunters may have considerable financial incentives. Effective conservation may depend on clearly identifying and defining target groups for behaviour change interventions (Jones et al., 2009). In Gola, a small number of 'high-impact' hunters likely capture a disproportionate share of harvest and profit – a pattern that is commonly reported (e.g. Abernethy and Ndong Obiang, 2010; Luz et al., 2017). In such systems, altering behaviour of a majority of hunters may have less impact than influencing the group of highest earning individuals using a more targeted approach.

Hunters and traders gave different reasons for reducing effort in bushmeat trade. Traders most frequently cited the risk of financial losses due to checkpoint confiscations, whereas most hunters cited increased involvement in activities such as farming. Checkpoints operate across Liberia and are relatively cheap to maintain. We found meat confiscation generated substantial financial risks, particularly for traders, many of whom had lost assets reaching hundreds of dollars. Most traders cited confiscation of meat alongside transportation costs as a major barrier to generating income from trade. While confiscation risk may act as a deterrent, it was insufficient to motivate hunters or traders to completely abandon their activities. A principle reason given for this was lack of alternative, equivalent, income sources. In contrast to traders, hunters most frequently cited doing other activities as a reason for reduced hunting effort. This implies that promotion of non-hunting activities which are time-demanding, but profitable, could be a successful conservation tool. As with the traders' responses, stated motivations do not constitute evidence of genuine behaviour change, and should be interpreted as factors which are perceived to influence choices. Nevertheless, the difference between hunters' and traders' responses provides useful hypotheses that could be formally tested: that traders are influenced by interventions to increase financial risks, while hunters respond best to increased demands on their time from alternative activities.

Our case-study demonstrates the need to consider the wider social context of hunting in order to obtain an accurate picture of bushmeat systems. For instance, the use of cash from bushmeat sales to boost other income sources merits further attention since this implies that simple models may not capture the true economic contribution of bushmeat. Nearly a third of hunters in this study maintained specific business partnerships with traders, and credit arrangements between the two groups were varied and complex. This underlying structure has implications for the design of interventions such as small loans schemes which are likely to influence hunter-trader relations. Trust and cooperation between actors may also be influential. Untrustworthiness of hunters was seen by traders as a significant barrier for generating profit, while a small number of hunters mentioned break-down of trading partnerships as motivation for decreasing their hunting effort. The nature of hunter-trader relationships may be revealing and could be influenced by conservation actions. For instance, Nielsen et al. (2016) report a system in Tanzania in which hunters advanced credit to traders – the reverse of what was observed in our study. This difference may be linked to differences in the risk and profit experienced by hunters and traders, with the implication that hunter-trader dynamics may be sensitive to interventions such as law enforcement. Trust can promote sustainable management of resources such as bushmeat by facilitating cooperative behaviour (Bouma et al., 2017; Vollan et al., 2013). However, our results imply that higher trust and cooperation in hunter and trader partnerships may promote over-hunting by minimising the financial risks and uncertainty faced by both parties. More generally, one-to-one relationships could make hunting systems more resistant to interventions by creating social expectations and obligations. A clearer understanding of social dynamics in bushmeat systems, and the way these are affected by conservation actions, could improve the design of interventions.

5. Conclusions

Bushmeat hunting in Liberia has received little research attention but is a major threat for endangered species in the region (Greengrass, 2016; Taylor et al., 2015). Our case-study illustrates the challenge of sustainable management of bushmeat resources in the face of large financial incentives and high livelihood dependence on wildlife. We found that motivations differed between hunters and traders, suggesting a promising direction for future work lies in determining whether livelihood support and law enforcement may be more effectively targeted. Social structures and processes such as interpersonal trust, were seen to be influential and merit closer attention in bushmeat research.

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Appendix A

Table A.1
Species harvested by 208 hunters over 999 hunting days in the Gola Forest, based on recall from most recent hunting trip. Ordered by percentage of total biomass.

Species	Species group	number of carcasses	total biomass (kg)	percent of all carcasses	percent of total biomass	destination of carcasses
Cephalophus dorsalis	Medium ungulate	500	10,000.0	23.1	27.7	Urban + local
Philantomba maxwellii	Small ungulate	811	6940.3	37.4	19.2	Urban + local
Syncerus caffer nanus	Large ungulate	11	6519.3	0.5	18.0	Urban + local
Potamochoerus porcus	Large ungulate	49	3430.0	2.3	9.5	Urban + local
Cephalophus niger	Medium ungulate	117	2234.0	5.4	6.2	Urban + local
Hylochoerus meinertzhageni	Large ungulate	4	792.5	0.2	2.2	Urban + local
Cercocebus atys	Primate	114	791.3	5.3	2.2	Urban + local
Tragelaphus scriptus	Medium ungulate	17	735.3	0.8	2.0	Urban + local
Cephalophus jentinki	Large ungulate	9	616.4	0.4	1.7	Urban
Tragelaphus eurycerus	Large ungulate	2	542.0	0.1	1.5	Urban
Colobus polykomos	Primate	59	519.0	2.7	1.4	Urban + local
Hyemoschus aquaticus	Medium ungulate	46	499.1	2.1	1.4	Urban + local
Choeropsis liberiensis	Large ungulate	2	470.0	0.1	1.3	Urban
Atherurus africanus	Rodent	108	310.6	5.0	0.9	Urban + local
Monkey - undefined species	Primate	51	296.6[a]	2.4	0.8	Urban + local
Cercopithecus diana	Primate	59	257.2	2.7	0.7	Urban + local
Cercopithecus petaurista	Primate	70	226.4	3.2	0.6	Urban + local
Pan troglodytes verus	Primate	5	225.0	0.2	0.6	Urban
Piliocolobus badius	Primate	25	210.8	1.2	0.6	Urban + local
Thryonomys swinderianus	Rodent	33	123.8	1.5	0.3	Local
Cercopithecus campbelli	Primate	32	116.1	1.5	0.3	Urban + local
Panthera pardus	Carnivore	2	104.8	0.1	0.3	Urban
Cephalophus silvicultor	Large ungulate	1	62.0	0.0	0.2	Urban
Cephalophus ogilbyi ssp brookei	Medium ungulate	2	36.8	0.1	0.1	Urban
Crocodile[b]	Reptile	1	25.0[a]	0.0	0.1	Local
Nandinia binotata	Carnivore	9	19.5	0.4	0.1	Urban + local
Mongoose - undefined species	Carnivore	11	15.3[a]	0.5	< 0.1	Local
Agelastes meleagrides	Bird	16	13.0	0.7	< 0.1	Local
Large raptor or Palm-nut vulture	Bird	2	7.2[a]	0.1	< 0.1	Local
Manis tricuspis	Pangolin	1	1.5	< 0.1	< 0.1	Local

[a] For undefined species, body mass of the most commonly killed member of the species group were used based on information provided by hunters. For monkeys the mean adult body mass of all monkey species was used.
[b] *Osteolaemus tetraspis* or *Mecistops cataphractus*.

Appendix B

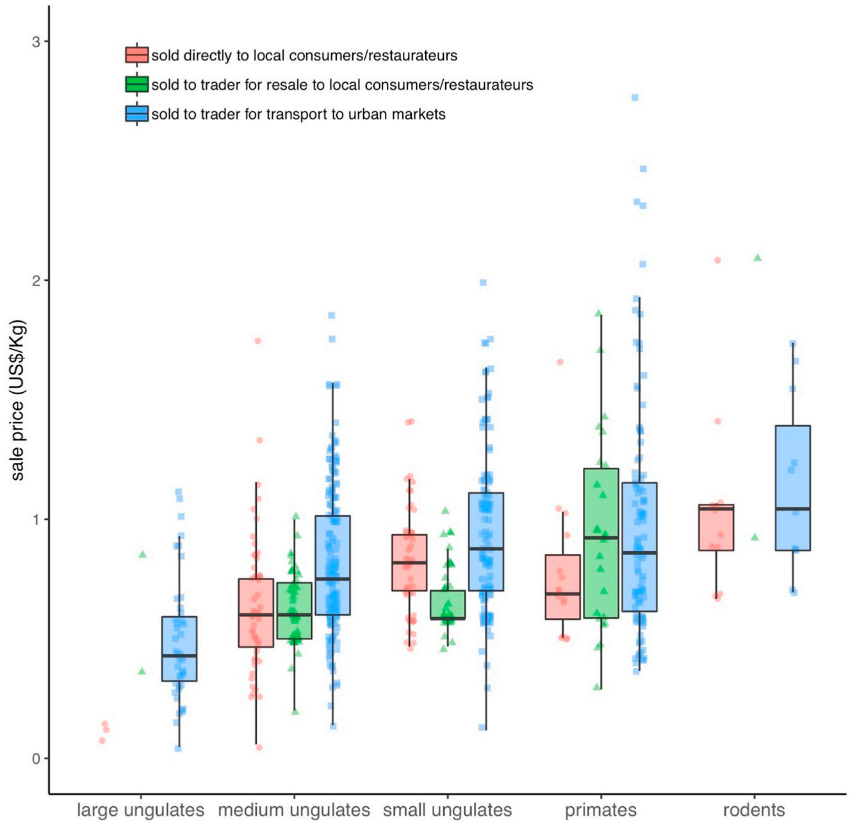

Fig. B.1. Prices received by hunters from bushmeat sold directly to local consumers or restaurateurs (red, circles), to traders intending to sell the meat to local consumers or restaurateurs (green, triangles), and to traders for transport to urban centres (blue, squares). Points show values of individual transactions (n = 759). Boxes indicate median and 25%–75% quartile range for cases with at least ten transactions, whiskers extend to 1.5xIQR beyond boxes. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

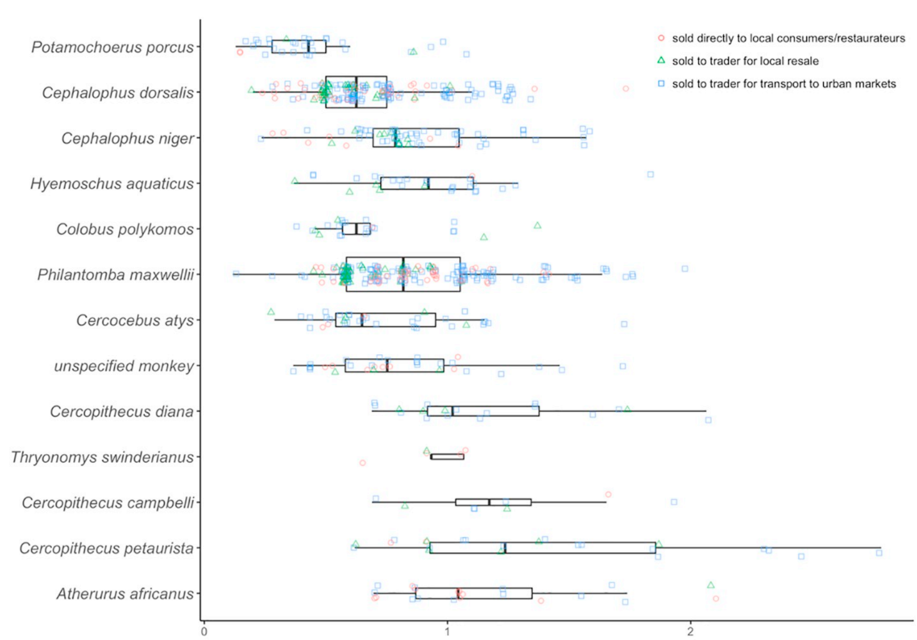

Fig. B.2. Sale prices received by hunters for the most frequently killed species, in order of body size. Points indicate hunters' sales directly to local consumers or restaurateurs (red circles), sales to traders for local resale (green triangles), or sales to traders for transport to urban markets (blue squares). Median and 25%–75% quartiles range are indicated by boxes, widths are proportional to the number of carcasses sold. Species are ordered by mean body size (smallest at the bottom). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Appendix C

Table C.1
Factors considered by traders to be the principle challenges of bushmeat trading, data from interviews with 50 traders.

Principle challenges for bushmeat traders (*example statements*)	Percentage of respondents
Government restrictions and law enforcement	62% (31)
"*FDA [Forestry Development Authority of Liberia] law*"	
"*the arresting of meat on the road*"	
Trustworthiness of hunters	12% (6)
"*you paid the hunters for the meat and you don't get it sometime*"	
"*some hunters will carry your money and don't come back*"	
"*we have to go after some of the hunter to get [our] goods*"	
"*to get dry meat from the hunter is not easy*"	
Poor road condition	12% (6)
"*bad road condition and huge transportation fare*"	
"*accessibility, poor road conditions*"	
Travelling long distances	8% (4)
"*moving from one place to another to get meat*"	
"*walking from place to another*"	
"*going on far distance to get the meat, sometime you don't see the hunter*"	
Conservation	4% (2)
"*Due to conservation*"	
Declining wildlife abundance	2% (1)
"*shortage of animals*"	
Other – personal	2% (1)

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Chapter 4. Audience segmentation to improve targeting of conservation interventions for hunters

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Contributed Paper

Audience segmentation to improve targeting of conservation interventions for hunters

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Abstract: *Audience segmentation could help improve the effectiveness of conservation interventions. Marketers use audience segmentation to define the target audience of a campaign. The technique involves subdividing a general population into groups that share similar profiles, such as sociodemographic or behavioral characteristics. Interventions are then designed to target the group or groups of interest. We explored the potential of audience segmentation for use in defining conservation target groups with a case study of hunters in Liberia. Using 2 data sets describing households (*n *= 476) and hunters (*n *= 205), we applied a clustering method in which infinite binomial mixture models group hunters and households according to livelihood and behavior variables and a simple method to define target groups based on hunting impact (hunting households and high-impact hunters). Clusters of hunters and households differed in their experiences with confiscation of catch at roadblocks and participation in livelihood-support programs, indicating that these interventions operate unevenly across subsets of the population. By contrast, the simple method masked these insights because profiles of hunting households and high-impact hunters were similar to those of the general population. Clustering results could be used to guide the development of livelihood and regulatory interventions. For example, a commonly promoted agricultural activity, cocoa farming, was practiced by only 2% (out of 87) of the largest hunter cluster of nonlocal gun hunters but was prevalent among local trappers, suggesting that assistance aimed at cocoa farmers is less appropriate for the former group. Our results support the use of audience segmentation across multiple variables to improve targeted intervention designs in conservation.*

Keywords: bushmeat, conservation marketing, Gola Forest, hunting, livelihood support, target audience, West Africa

Segmentación del Público para Mejorar la Focalización de las Intervenciones de Conservación para los Cazadores

Resumen: *La segmentación del público podría ayudar a mejorar la efectividad de las intervenciones de conservación. Los publicistas utilizan la segmentación del público para definir al público focal de una campaña. La técnica incluye la subdivisión de una población general en grupos que comparten perfiles similares, como las características socio-demográficas o de comportamiento. Después se diseñan las intervenciones para enfocarse en el grupo o los grupos de interés. Exploramos el potencial de la segmentación del público en el uso de la definición de grupos con objetivos de conservación usando el estudio de caso de los cazadores en Liberia. Con dos conjuntos de datos de descripciones de los hogares (*n *= 476) y de los cazadores (*n *= 205) aplicamos un método de agrupación en el cual los modelos de mezcla binomial infinita agruparon a los cazadores y a los hogares de acuerdo a las variables de sustento y de comportamiento. También aplicamos un método simple para definir los grupos focales con base en el impacto de la caza (hogares de cazadores y cazadores de alto impacto). Los grupos de cazadores y de hogares difirieron en experiencias con la confiscación de la caza en retenes y en participación dentro de programas de apoyo al sustento, lo que indica que estas*

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intervenciones operan disparejamente en los subconjuntos de la población. En contraste, el método simple enmascaró estas percepciones ya que los perfiles de los hogares de cazadores y de los cazadores de alto impacto fueron similares a los de la población general. La agrupación de los resultados podría usarse para guiar el desarrollo del sustento y de las intervenciones regulatorias. Por ejemplo, el cultivo de cacao, una actividad agrícola que se promueve frecuentemente, sólo lo practicaba el 2% (de 87) del mayor grupo de cazadores de los cazadores armados no locales, pero fue prevaleciente entre los trampeadores locales, lo que sugiere que la asistencia enfocada hacia los cultivadores de cacao es menos apropiada para el primer grupo. Nuestros resultados respaldan el uso de la segmentación del público en múltiples variables para mejorar los diseños de intervenciones focalizadas en la conservación.

Palabras clave: África occidental, apoyo al sustento, bosque de Gola, cacería, carne de caza, mercadotecnia de la conservación, público focal

摘要: *受众细分有助于提高保护干预措施的有效性。市场营销者用受众细分来确定活动的目标受众, 这项方法涉及将一般人群划分为具有相似特征 (如社会人口统计学或行为特征) 的多个亚群, 然后针对一个或多个亚群来设计干预措施。我们以利比亚的狩猎者为例, 探讨了受众细分在确定保护的目标群体方面的应用潜力。我们利用描述家庭 (n = 476) 和狩猎者 (n = 205) 的两个数据集, 采取聚类方法根据生计和行为变量用无限二项混合模型对狩猎者和家庭进行分类, 同时用一个简单方法根据狩猎影响确定了目标群体 (狩猎家庭和高影响狩猎者)。狩猎者和家庭聚类群集间的差别在于在路障检查中被没收猎获物的经历和生计支持项目的参与情况, 表明干预措施不能均衡地作用于人群的不同亚群。相比之下, 用简单方法不能得到这些发现, 因为狩猎家庭和高影响猎人与普通人群的特征相似。聚类结果还可用于指导生计发展和监管干预。举例来说, 对于当地大力推广的可可种植这项农业活动, 外来用枪狩猎者的最大聚类群集中只有 2% 的人 (共 87 人) 参与, 但在本地设陷阱的人中参与度却很高, 这表明针对可可种植者的援助并不适用于前者。我们的结果支持了利用考虑多个变量的受众细分来提高保护中的针对性干预措施的设计。***【翻译: 胡怡思; 审校: 聂永刚】***

关键词: 保护市场学, 丛林肉, 戈拉森林, 生计支持, 目标受众, 西非, 狩猎

Introduction

Conservation practitioners are frequently faced with the challenge of influencing human behavior and must make choices about which approach to use in any given site. Conservation interventions are typically implemented using a combination of actions that require managers to make site-specific decisions about which to use. Such decisions should be based on a clear understanding of who the action intends to influence (Veríssimo 2013; Reddy et al. 2017) given that different types of people are likely to be responsive to different mechanisms (Kotler & Lee 2008). An appropriately defined target group is therefore fundamental to guide intervention design, yet many projects either fail to specify who they aim to influence or employ a broad definition such as all residents within a geographic area (Spiteri & Nepal 2006). As a result, intervention designs may be broadly aimed at an average person across an entire community, which is inefficient if the population is comprised of heterogeneous groups responding differently to interventions (Agrawal & Gibson 1999; Wright et al. 2015). Intervention designs may be improved by paying greater attention to the process and methods of defining target groups.

Techniques from marketing may be well suited to improve the way target groups are defined in conservation. Audience segmentation is a commonly used approach of subdividing populations into groups with shared characteristics, such as sociodemographic, behavioral, or psychographic profiles (Wedel & Kamakura 2012). Ideally, segmentation defines groups of individuals who can be expected to respond similarly to interventions, allowing managers to design approaches that are oriented to target the specific group or groups of interest (Kotler & Lee 2008). Effective segmentation depends on selecting appropriate characteristics for defining groups (Wedel & Kamakura 2012). These should be variables linked to behavior and which have practical consequences for management decisions. Attributes most commonly used in marketing include broad demographic, socioeconomic, and geographic factors, but increasingly focus is on individual traits, such as personality, attitudes, beliefs, lifestyle, risk preference, and social group affiliations (Lee et al. 2014; Hardcastle & Hagger 2016).

Segmentation has rarely been applied in conservation, but it is a valuable tool in social marketing (Kotler & Lee 2008). For example, segmentation has been used to design public health campaigns that target those most at risk (Forthofer & Bryant 2000; Dietrich et al. 2015) or most likely to be responsive to interventions (Rimal et al. 2009). Key environmental problems, such as climate change, energy use, transport, and sustainable lifestyle choices, have also been the subject of segmentation studies to guide policy and messaging campaigns (Anable 2005; Maibach et al. 2011; McKenzie-Mohr et al. 2011; Poortinga & Darnton 2016). In a rare example of segmentation in conservation, Zabala et al. (2017) applied the approach to guide the introduction of conservation-friendly farming practices in Mexico by using attitude statements of farmers to define groups of early adopters and followers. Harrison et al. (2015) also used a straightforward segmentation of authorized versus unauthorized resource users to generate valuable management insight in a Ugandan protected area.

There are currently no methodological guidelines to inform the process of defining target groups in conservation, despite this being of great practical interest to managers. Methods used within marketing to subdivide populations range from the relatively simplistic approach of splitting populations according to single variables, to more complex clustering approaches that differentiate groups across multiple variables (Wedel & Kamakura 2012). A major challenge in conservation is the gap in understanding of factors that underpin behavior. Detailed psychographic data sets of the sort used in marketing studies are rarely available or difficult to obtain where target behaviors are illegal (Gavin et al. 2010). Given these typical constraints, segmentation based on multiple variables may perform little better than simplistic target group definitions based on a single trait, such as whether or not someone hunts. Multivariate methods may have higher costs associated with data collection and analysis, so a practical management consideration is whether these costs are justified by improved conservation outcomes.

We evaluated segmentation approaches with a case study of bushmeat hunting in the Gola Forest, Liberia. Hunting reduction is a conservation priority for many sites across the tropics (Benítez-López et al. 2017; Cronin et al. 2017). However, bushmeat provides a valuable source of food and income for rural populations who are often economically vulnerable (e.g., Fa et al. 2003). Therefore, many hunting reduction programs have a human welfare element (Davies 2002), and interventions generally fall into 5 categories: support for sustainable livelihoods; provision of alternative protein sources; financial mechanisms; regulatory and enforcement mechanisms; and education and awareness raising campaigns (van Vliet 2011). The most effective hunting interventions are likely to be highly context specific, so managers require a clear understanding of the intended target group or groups to guide intervention design.

We assessed the usefulness of 2 audience-segmentation methods under realistic constraints of site-based conservation programs: a cluster method, where groups were differentiated based on multiple variables describing livelihoods and behavior, and a simple method, where the population was divided into 2 groups of either high or low hunting impact. We asked do segmentation methods generate insights to guide decisions about appropriate livelihood support interventions and does either segmentation approach (cluster or simple) differentiate groups with profiles that suggest targeted intervention design is appropriate?

Methods

Study Site

We collected data from July 2016 to July 2017 in Kongba district, Liberia, at the site of a community-based conservation project, GolaMA, which started in 2014 (GRNP 2015). Project activities focused on establishment of conservation-friendly community forests, based on livelihood-support approaches and hunting regulations. Overhunting is a primary conservation threat in Liberia. Wild meat is consumed widely (Junker et al. 2015; Ordaz-Németh et al. 2017) and thus provides substantial income for hunters and traders (Hoyt 2004; Greengrass 2016). Hunting of species listed as protected under the Wildlife Act (1988, revised 2016) is illegal, as is hunting in national parks, although both types of hunting are widespread (S.J., personal observation). The Gola Forest National Park (established 2016) is adjacent to the study site, and wild meat being transported to the capital city of Monrovia is irregularly confiscated at a checkpoint. The west of the study area extends to the Sierra Leone border and is a short distance from the Gola Rainforest National Park (Fig. 1).

The site retains relatively high forest cover and low population density. Economic immigration for mining, logging, and hunting has resulted in an ethnically diverse population with 20 tribes represented. At the time of the study, two-thirds of the population (65%) belonged to 1 of 3 dominant tribes (Gola, Mende, and Kissi) (Supporting Information). Residents self-identify as local or nonlocal citizens. Those who consider themselves local typically have at least 1 parent with local ancestry. Residents who identify as nonlocal are typically individuals born outside the district or without local ancestry, such that long-term residents and recent arrivals may identify as nonlocal. The largest group of nonlocals was from Nimba county in Liberia (about 26% of nonlocals), and 15% of all residents were Sierra Leonean nationals. At least 7% of the population was transient migrants.

Data Collection

We collected data through questionnaires administered during face-to-face interviews (Supporting Information). Hunting is an everyday activity in Liberia and is practiced openly, but some degree of social desirability bias is likely given that it is illegal (Nuno & St John 2014). However, an initial pilot study suggested that most hunters were willing to talk openly about their activities, and we judged the level of bias in data obtained from direct questioning to be acceptably low for our purposes. Ethical approval for the use of human subjects was obtained from the Royal Holloway University of London Research Ethics Committee.

The sample included 18 villages, consisting of all villages that participated in the GolaMA conservation

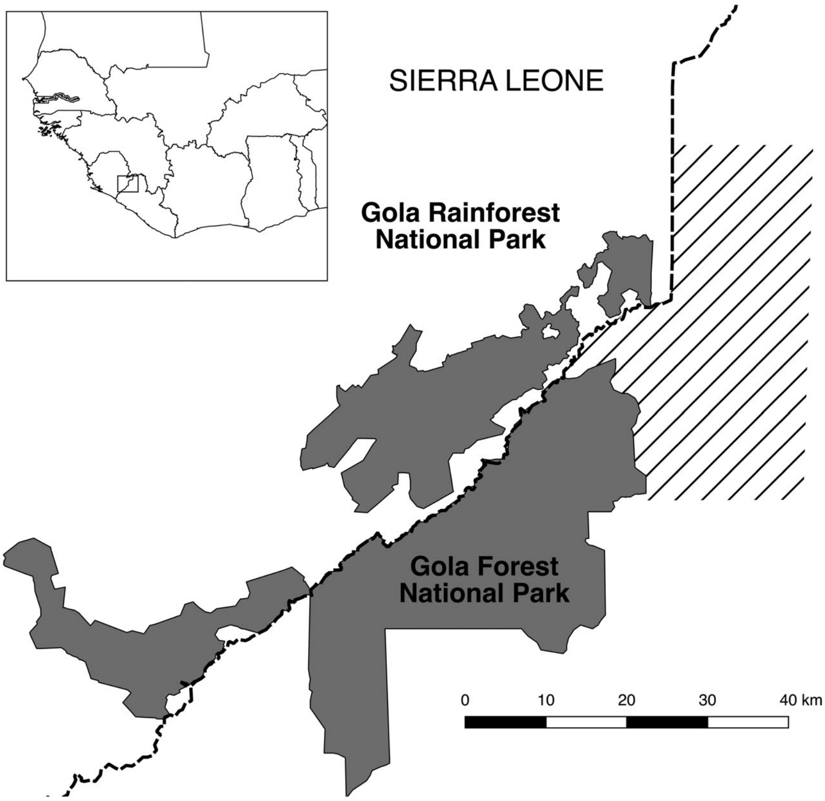

Figure 1. Study site location (diagonal lines) in Liberia (gray, protected areas; dashed line, border).

project and 2 neighboring villages (Fig. 1). The latter were selected based on their geographic proximity and had similar sociodemographic characteristics. In each village, we surveyed households and hunters separately. The household survey included all households, except in the largest village where an estimated 60% of households were surveyed (mean households per village = 28, range = 2–111). The hunter survey included all identified hunters in all villages and semipermanent camps that came under village jurisdiction (mean hunters per village = 10.8, range = 0–28). Hunters were identified during the household survey, through key informants and snow-ball sampling. If a hunter or household was not initially available, interviewers returned at least 3 times. It was not possible to match the hunter and household surveys because hunters were rarely encountered at their homes, and nonunique names created ambiguity in determining which household a hunter belonged to.

Questionnaires for the household survey were used to obtain information about livelihood activities and demography, and those for hunters contained additional questions about hunting behavior (Table 1). Estimates of mean biomass harvest for each hunter were derived from the total estimated body mass of their most recent catch, divided by the duration of both the hunting trip and days spent resting in the town. Hunters reported the composition of their last catch and the total estimated body mass was calculated using mean adult values for each species from Kingdon (2015) and Jones et al. (2009).

Simple and Cluster Methods

We defined 2 simple target groups: hunting households, based on the household survey, and high-impact hunters, based on the hunter survey (Table 1).

We performed separate cluster analyses on the household and hunter data sets with infinite binomial mixture models implemented with the R package BayesBinMix (R Core Development Team 2014; Papastamoulis & Rattray 2017). Cluster assignment used the equivalence classes representative algorithm (Papastamoulis 2014). A truncated Poisson distribution was used as the prior distribution for cluster number, allowing a maximum of 20 clusters. We used a metropolis-coupled Markov chain Monte Carlo sampling algorithm with parallel tempering to improve mixing. Fifteen heated parallel chains were run with 20,000 iterations. Convergence was assessed with the Geweke diagnostic (Geweke 1992).

Variables used for clustering related to livelihood activities, citizenship, and hunting behavior are listed in Table 1. Livelihood activities relevant to intervention design and principle candidates for support interventions by the GolaMA project were cocoa farming, palm farming, small-scale mining, and petty-goods trading. These variables were chosen to be simple for managers to interpret without prior knowledge of which factors mediate behavior and which could be measured where psychological scales have yet to be developed and validated. Incorporating a broader set of sociodemographic

Table 1. Variables and criteria used to define hunter and household target groups for conservation interventions.

*Method to define target group**	*Variable type*	*Household data set*	*Hunter data set*
Cluster method	citizenship	household head is local	hunter is local
	livelihood activities	palm farming cocoa farming small-scale mining petty-goods trading biennial agriculture annual agriculture charcoal production fishing salaried employment	palm farming cocoa farming small-scale mining petty-goods trading skilled craft
	hunting behavior	hunting by any household member	harvested biomass >8.5 kg/d hunts >14 d/month uses gun uses snares estimated income >$100/d hunting
Simple method	hunting behavior	hunting by any household member (hunting households)	hunters with highest per capita impact collectively responsible for 50% of total harvest in study (high-impact hunters)

**The cluster method defines groups based on their similarity across multiple binomial variables, the simple method defines groups from a single criterion.*

and psychographic variables was beyond the scope of this study, which is intended to provide an initial assessment of segmentation in a novel context. Continuous variables were transformed to binary responses with cutoff values selected to provide straightforward management interpretations. Biomass harvest was coded as 1 for values exceeding the mean body mass of the most frequently killed species (maxwell's duiker [*Philantomba maxwelli*]) and hunters' self-estimated profit was coded as 1 if in excess of US$100/month, a typical entry wage from local employment sources.

Generation of Insights to Guide Intervention Targeting

Livelihood profiles represent basic information to guide decisions about appropriate livelihood support interventions. We compared the prevalence of livelihood activities in clusters and simple groups with those of the complete data sets to explore whether segmentation supplied novel perspectives. Group profiles were supplemented with qualitative descriptions based on sociodemographic information: age, marital status, education, and household size. We defined education as high school level if hunters had at least 6 years of formal education (hunter data set) or if any member of the household did (household data set).

Segmentation should group people who may respond similarly to a given intervention in order to guide intervention targeting. Interventions had not been fully implemented at the time of the study, so direct measures of intervention response were unavailable. Instead, we tested whether groups differed for the following indirect measures. For households, we evaluate participation in livelihood support programs being piloted by the GolaMA project because this could indicate future participation (Ajzen 2011). Available programs were beekeeping, cocoa farmer training, small loans groups, and community agriculture. We considered only villages where at least 1 program was offered and combined programs so households either did or did not engage in a livelihood intervention. For hunters, we evaluated killing of any of 4 high-profile protected species (forest elephant [*Loxodonta cyclotis*], pygmy hippopotamus [*Hexaprotodon liberiensis*], western chimpanzee [*Pan troglodytes verus*], or leopard [*Panthera pardus*]) and experience of confiscation of catch by authorities, usually taking place at road blocks. The former indicated hunters with the means and disposition to target large-bodied species, which are widely known to be protected by law, and the latter was a combined measure of both exposure to and tolerance of law enforcement efforts.

We use Pearson's chi-square to evaluate distribution of these traits between clusters and simple target groups. Analysis of variance was used to evaluate group differences in age and household size.

Results

Hunting in the Study Area

Of the 476 households in the survey, 39% had members who hunted and 26% had been hunting during the

Table 2. Descriptive summary of household groups based on results of cluster analysis.

Household group	*n*	*Citizenship and hunting prevalence*	*Livelihood activities high prevalence*	*Livelihood activities low prevalence*
Nonlocal farmers	128	96% nonlocal 61% hunt	annual agriculture 98% petty-goods trade 70% palm farming 51% mining 38%	cocoa 27% charcoal production 9%
Local farmers	176	100% local 40% hunt	annual agriculture 97% cocoa 89% petty-goods trade 65%	salaried employment 0% mining 15%
Nonlocal hunting households	31	84% nonlocal 97% hunt	hunting 97%	annual agriculture 16% cocoa 0%
Merchants and salaried workers	63	74% local 3% hunt	petty-goods trade 98% salaried employment 49%	hunting 3%
Nonlocal miners	68	81% nonlocal 12% hunt	mining 97% petty-goods trade 89% charcoal production 32%	cocoa 4% palm farming 3%
Local plantation farmers	10	90% local 0% hunt	annual agriculture 100% cocoa 90% palm farming 60%	fishing 0% mining 0% petty-goods trade 0%

previous week. Local citizens headed 54% of all households and 45% of hunting households. Of the 205 hunters interviewed in the survey, 41% were local citizens, 75% used guns to hunt, and 56% used snares. Mean trip length was 3.9 d (SD 3.0) and mean estimated biomass harvest was 14.4 kg/d (SD 14.5).

Household Clusters

The most likely number of clusters was 6 (probability 0.53). Size varied from 10 to 176 households. The 2 largest clusters held 64% of all households. Citizenship was a prominent feature defining clusters (Table 2); the largest cluster held almost 70% of all local-headed households. High school education (of any household member) was unevenly distributed across clusters ($n = 471$, $\chi^2 = 15.09$, df = 5, $p < 0.01$). The clusters were labeled for convenience (Table 2). Local farmers had a relatively low rate of high school education (37%) compared with 60% for nonlocal hunting households, merchants, salaried workers, and local plantation farmers (Supporting Information).

The cluster of nonlocal farmers contained 128 households, of which 96% were nonlocal. Most (98%) practiced annual or biennial agriculture. The majority (61%) were hunting households—representing 40% of all hunting households in the sample. Relatively common nonhunting activities were petty-goods trade (70%), palm farming (51%), and mining (38%).

The cluster of local farmers contained 176 households, all of which were local. Hunting was practiced by 40% of these households. Most households (97%) practiced annual or biennial agriculture, 89% were cocoa farming households, and 65% traded petty goods. Mean household size was the largest of any group (mean number of adults 3.4 [SD 2.1], mean children 3.8 [SD 1.8]) (Supporting Information).

The cluster of nonlocal hunting households contained 31 households, of which 84% were nonlocal and 97% hunted. None were cocoa farming households, and few farmed annual or biennial crops (16% and 23%, respectively), distinguishing this group from the nonlocal farmers, many of whom also hunted.

The merchant and salaried workers' cluster contained 63 households, of which 74% were local and 3% hunted. Most (98%) traded petty goods, and 49% had some form of employment—representing 66% of all households with employment.

The nonlocal miners' cluster contained 68 households, of which 81% were nonlocal, 97% engaged in mining, and 12% hunted. Cocoa and palm farming were rare (4% and 3%, respectively). Most (72%) were resident in the same village. Households had fewer children on average than other groups (mean [SD] = 2.1 [1.7] compared with 3.3 [1.9] across all households) (Supporting Information).

The cluster of local plantation farmers was the smallest (10 households), and all households farmed cocoa or palm, grew subsistence crops, and gained additional income from selling charcoal, but they lacked other income sources. No households hunted. Six were resident in the same village.

Table 3. Descriptive summary of hunter groups based on results of cluster analysis.

Hunter group	*n*	*Citizenship, hunting method*	*Livelihood activities high prevalence*	*Livelihood activities low prevalence*	*Mean hunting effort, offtake, and income (SD)*
Nonlocal gun hunters	87	98% nonlocal 100% use guns 49% use snares	mining 24% petty-goods trade 22%	cocoa 2% palm farming 9%	intermediate offtake 14.1 kg/d (12.8) high effort 14.7 d/month (5.32) intermediate income (61% earn over $100/month)
Local trappers	31	87% local 26% use guns 100% use snares	palm 65% cocoa 48% mining 23%	petty-goods trade 13%	high offtake 19.7 kg/d (15.8) intermediate effort 11.3 d/month (5.62) high income (81% earn over $100/month)
Local gun hunters	49	90% local 100% use guns 17% use snares	cocoa 55% skilled craftsmen 14%	mining 8%	low offtake 11.8 kg/d (16.5) low effort 8.78 d/month (4.42) intermediate income (62% earn over $100/month)
Nonlocal trappers	28	85% nonlocal 0% use guns 100% use snares	petty-goods trade 29%	cocoa 7% palm farming 4%	intermediate offtake 14.8 kg/d (15.3) intermediate effort 11.4 d/month (5.16) low income (15% earn over $100/month)
Occasional hunters	10	80% local 90% use guns 80% use snares	petty-goods trade 100% cocoa 90% palm 80% mining 70%	none	low offtake 10.8 kg/d (7.07) low effort 8.4 d/month (5.36) low income (none earn over $100/month)

Hunter Clusters

Hunters fell into 5 clusters (probability of 0.58). Size ranged from 10 to 87 hunters. Citizenship and hunting methods were prominent defining features (Table 3). Marital status or number of children was not associated with cluster membership. Age differed significantly between clusters ($F_{4,194} = 4.16$, $p<0.01$). High school education was not evenly distributed across clusters ($n = 202$, $\chi^2 = 10.03$, df $= 4$, $p = 0.04$) (Supporting Information).

The cluster of nonlocal gun hunters contained 87 hunters, 98% of whom were nonlocal citizens (residents with nonlocal ancestry). Mean residency in villages was 9.2 years (SD 5.1). All used guns. Most hunted over 14 d/month (78%), and 61% generated over $100/month. Mining and petty trading were practiced by some individuals (24% and 22%, respectively), but other income sources were rare. Rates of high school education were the highest of any group (47% relative to 35% among all hunters).

The cluster of local trappers contained 31 hunters; 87% were local and all used snares. Mean offtake per hunter was higher than any other group (19.7 kg/d), but only 33% spent over 14 d per month hunting. Income from palm, cocoa, and mining was relatively common (65%, 48%, and 23%, respectively). Local trappers were younger than nonlocal gun hunters (mean age [SD] = 34.6 years [10.7] and 43.6 years [11.1], respectively, Tukey test difference in means = 9.0, 95% CI 2.7–15.3, $p < 0.01$). Only 26% had high school education.

The cluster of local gun hunters contained 49 hunters, 90% were local and all used guns. Despite relatively low offtake (mean = 10.8 kg/d), most generated over $100/month (62%). This group showed the highest prevalence of skilled crafts people (14%) and few miners (8%). Cocoa and palm were relatively common (55%, 37%, respectively). Mean residency in villages was longer than any group (mean [SD] = 24.1 years [17.0] relative to mean [SD] = 14.4 years [12.8] among all hunters) (Supporting Information).

The nonlocal trapper cluster contained 28 hunters, of which 85% were nonlocal. All only used snares to hunt. Effort and offtake were intermediate, but only 15% generated over $100/month. There was low prevalence of income from nonhunting livelihoods. Members had settled in villages relatively recently compared with other groups (mean residency [SD] = 8.5 years [8.0]) (Supporting Information).

The cluster of occasional hunters contained only 10 members. Eight were local and 9 used guns. Most had multiple income sources. All were petty traders, and cocoa, palm, and mining were prevalent. None earned over \$100/month, and most (90%) spent under 14 d/month hunting.

Generation of Insights to Guide Intervention Targeting

The cluster method produced groups which differed in livelihood profiles compared to the simple method of no targeting for households and hunters. Among 4 activities considered candidates for support interventions, the most prevalent was petty trading among all households (no targeting, 73%) and hunting households (simple targeting, 72%), but cocoa farming among the largest cluster of local farmers (89%). The prevalence of livelihood activities in the simple target groups was generally similar to the general population (Supporting Information).

Among hunters, mining was prevalent in the largest cluster of nonlocal gun hunters (24%), whereas this consistently ranked below other activities under simple or no targeting (Supporting Information). Livelihood activity profiles of hunters differed from those of households, with prevalence of petty trading being much higher among households (72%) than hunters (23%).

Pilot livelihood support programmes were offered to 184 households, of which 82% (151 households) participated. It was not possible to test whether participation was evenly distributed across all clusters because low expected values for small clusters violated the assumptions of Pearson's chi-square test. Therefore, we only compared the 2 largest clusters. Participation was unevenly distributed ($n = 156$, $\chi^2 = 6.23$, df $= 1$, $p = 0.013$). Nonlocal farmer households had lower participation (67% of 39 households) than the expected value of 81.4%, whereas local farmers had higher participation (86% of 117 households). In contrast, participation had no significant association with the simple target groups of hunting and nonhunting households (85% of 66 hunting households and 81% of 118 nonhunting households participated, $n = 184$, $\chi^2 = 0.29$, df $= 1$, $p = 0.59$).

Prevalence of killing any of 4 protected species was 42% across all hunters who were asked this question ($n = 131$). A total of 34% had killed western chimpanzee during their hunting career, 18% had killed pygmy hippopotamus, 18% had killed leopard, and 2% had killed forest elephant. There was no association between prevalence of protected species killing and groups defined using either the simple or cluster method (Table 4) ($n = 131$, simple method: $\chi^2 = 2.26$ df $= 1$, $p = 0.13$; cluster method: $\chi^2 = 6.95$, df $= 4$, $p = 0.14$). This was also true for western Chimpanzees specifically ($n = 131$, simple method: $\chi^2 = 1.01$, df $= 1$, $p = 0.31$; cluster method $\chi^2 = 1.01$, df $= 1$, $p = 0.31$). It was not possible to evaluate the other species individually due to low expected values which violated test assumptions.

A total of 45% of hunters had previously had their catch confiscated by authorities. This was significantly associated with clusters ($n = 130$, $\chi^2 = 28.08$, df $= 4$, $p < 0.0001$), but not the simple target groups of low- versus high-impact hunters ($\chi^2 = 1.09$ e-31, df $= 1$, $p = 1.00$). In the largest cluster, nonlocal gun hunters, 67% of hunters had a catch confiscated, but only 11% of local trappers had a catch confiscated, the second largest cluster.

Table 4. Protected species killing and catch confiscation among hunter groups defined based on the cluster and simple methods.

Method	*Proportion that killed a protected species (sample size)*	*Proportion that experienced confiscation (sample size)*
Cluster	$\chi^2 = 6.95$, $p = 0.40$	$\chi^2 = 28.08$, $p < 0.0001$
nonlocal gun hunters	0.42 (55)	0.67 (55)
local trappers	0.42 (19)	0.11 (18)
local gun hunters	0.53 (32)	0.31 (32)
nonlocal trappers	0.13 (15)	0.6 (15)
occasional hunters	0.5 (10)	0.1 (10)
Simple	$\chi^2 = 1.50$, $p = 0.22$	$\chi^2 = 2.47$ e-31, $p = 1$
high-impact hunters	0.60 (15)	0.43 (14)
low-impact hunters	0.40 (116)	0.54 (116)
All hunters	0.42 (131)	0.45 (130)

Discussion

Valuable insights for intervention design were obtained from a cluster method to subdivide households and hunters. By contrast, the simple approach of defining target groups based only on hunting impact (hunting households and high-impact hunters) was relatively uninformative with respect to targeting because these groups had profiles that were similar to the general population. Cluster profiles offered a basis to improve intervention targeting and differentiated groups that are likely to differ in responsiveness to regulatory and livelihood mechanisms, despite being limited to basic livelihood and behavior variables. This implies that segmentation could be successfully applied in many conservation settings, with further advantages expected from dedicated studies that more directly focus on human behavior. Effective targeting is likely to be achieved by considering multiple variables to define target groups, whereas using overly simplistic criteria or failing to define target groups at all may contribute to poorly designed interventions.

Cluster profiles gave insight into targeting of livelihood support interventions and provided a compelling case that distinct needs of different groups are important considerations for intervention design. For instance, the 2 largest hunter clusters, nonlocal gun hunters and local trappers, differed notably in prevalence of cocoa and palm farming. Livelihood support programmes which aim to increase income from cocoa and palm farming are commonly implemented across West Africa, often based on the assumption that supporting these livelihoods will lead to a decrease in hunting (Roe et al. 2015). Our findings imply that supporting cocoa or palm farmers may be appropriate for local trappers, but a significant subset of hunters, the nonlocal gun hunters, currently have little involvement in these activities and thus are unlikely to participate. This was mirrored at the household level, with the largest cluster comprising mainly cocoa farmers (89%), whereas only 27% of the nonlocal farmer cluster had cocoa plantations. This pattern could be due to barriers preventing nonlocal citizens from farming cocoa, such as challenges of land-tenure security or a stronger preference for shorter term investments due to plans to return to their original home (Sward 2017; S.J., personal observation). The simple approach to defining target groups masked this pattern and could lead managers toward a more simplistic impression that cocoa is relatively prevalent among high-impact hunters or hunting households.

Participation in livelihood programmes and exposure to hunting penalties were found to differ between clusters, revealing that current livelihood and law enforcement mechanisms operate differently across sections of society. Given these traits were not differentiated between groups defined simply as having high versus low hunting impact, this supports an argument that clustering identifies groups with distinct requirements when it comes to intervention design, whereas simpler approaches may not. Ways to improve both the effectiveness and equitability of interventions could be revealed by determining the mechanisms behind these patterns. For instance, households in the nonlocal farmer cluster had lower rates of participation in pilot-phase livelihood support programmes than the local farmers, suggesting that such programmes may not be equally accessible to both groups. We also found that most hunters in the cluster of nonlocal gun hunters had been penalized for hunting (67%), whereas this was far lower among local trappers (11%). Reasons for this could include trading patterns, because local trappers may export a smaller proportion of catch and face less risk of confiscation. However, bias in the enforcement of laws may also play a role because locals could be expected to have stronger interpersonal relationships with park staff. Evidently, these penalties had proven ineffective as hunting deterrents for those in our sample, whereas any individuals who had ceased hunting due to law enforcement efforts would not have been included in our study. In contrast, killing of large-bodied protected species did not differ for clusters or simply defined groups, suggesting that neither segmentation approach could offer insight for targeting when it comes to this aspect of hunting behavior. Whether or not hunters had killed protected species during their career may represent an imprecise indicator of multiple factors, including hunters' skill, methods, and awareness of protected species laws, which do not appear to have been captured in the cluster analysis.

An unforeseen advantage of segmentation may be to help identify potentially vulnerable groups within the population. We found a relatively small subset of households, the nonlocal hunting household cluster, had a high prevalence of hunting but relatively few other income sources and particularly low participation in shifting agriculture or plantation cropping. As incomers, these households do not have equal status with local citizens when it comes to many aspects of land tenure, decision making, or local judicial processes and could face high costs of hunting reductions that may not be adequately offset by agricultural livelihood support. Nonlocal citizens had typically distinct livelihood portfolios and hunting behavior from locals, both at the scale of households and individual hunters. Kümpel et al. (2009) similarly found that immigrant hunters have distinct behavioral profiles from locals. This pattern is particularly relevant in the context of community-based natural resource management which seeks to shift control of resources to local management bodies while ensuring that opportunity costs are not unduly borne by the poorest (Duffy et al. 2016). A major challenge is ensuring equitable distribution of benefits and power (Law et al. 2018), and marginalization of nonlocal immigrants could be a concern, particularly if livelihood patterns are a result of inequalities such as land tenure rights.

Our case study describes a promising first step in developing segmentation as a tool in site-based conservation. However, further work is required to realize the potential of this technique, particularly when it comes to identifying appropriate variables for clustering. Many aspects of behavior are likely to be underpinned by psychographic traits such as risk attitudes and personality (Boslaugh et al. 2005; Hunecke et al. 2010; Wolff et al. 2010) and an understanding of these could generate deeper insight for intervention design. Moving beyond socioeconomic descriptions toward approaches drawing on behavioral theory and fields such as psychology may do much to improve intervention design (Saunders et al. 2006; Bennett et al. 2017; St John et al. 2018) and leverage the potential of tools such as audience segmentation. There is also a need to place relevant psychosocial attributes more squarely at the heart of monitoring programs to improve understanding of factors that facilitate behavior-change outcomes.

Translating cluster attributes into practical recommendations for intervention design requires a rigorous process of testing and development (Verissimo et al. 2011), which can be facilitated by adaptive management (McCarthy & Possingham 2007). An important limitation of our study is that we did not directly assess peoples' responses to interventions. A priority for future segmentation studies should be to integrate a robust validation of groups into the monitoring and development process, based on direct measures of behavior (Boslaugh et al. 2005). This will also contribute to understanding of behavior-change mechanisms more generally and build a stronger evidence base to guide decision making. Segmentation analysis over larger scales could generate valuable insights for regional conservation planning, and an interesting question remains of whether cluster profiles identified in our study are consistent at other sites.

Given its current role in social and commercial marketing applications, audience segmentation could be a valuable tool that is relevant in many conservation settings. The approach of defining population structure across multiple variables provides managers with a more comprehensive view of who they intend to influence. This promotes the view that populations are composed of heterogeneous groups and places their different needs and behavior at the center of decision making. Our case study demonstrates that segmentation can be informative even when only basic livelihood data sets are used, and we encourage more widespread adoption of the approach within the conservation community.

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Supporting Information

Livelihood and behavior profiles of groups defined using the cluster and simple methods (Appendix S1), sociodemographic descriptions of groups defined using the cluster and simple methods (Appendix S2), demographic information (Appendix S3), and questionnaires administered to households and hunters (Appendix S4) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

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Supporting Information (S1)

Table 1. Profiles of household groups defined using clustering and simple methods, with proportions of each group that engaged in livelihood activities.

Target group	Group Size (number of households)	local citizen	biennial crops	annual crops	hunting	fishing	char-coal	employment	cocoa	palm	mining	petty goods trade
CLUSTER METHOD												
Non-local farmers	128	0.04	0.98	0.98	0.61	0.62	0.09	0.04	0.27	0.51	0.38	0.70
Local farmers	176	1.00	0.97	0.98	0.40	0.82	0.15	0	0.89	0.55	0.15	0.65
Non-local hunting households	31	0.16	0.23	0.16	0.97	0.48	0.16	0	0	0.19	0.26	0.63
Non-local miners	68	0.19	0.85	0.38	0.12	0.16	0.32	0.13	0.04	0.03	0.97	0.89
Merchants and salaried workers	63	0.76	0.75	0.68	0.03	0.63	0.06	0.49	0.27	0.02	0.10	0.98
Local plantation farmers	10	0.90	1.00	0.8	0	0	0.7	0.2	0.90	0.6	0	0
SIMPLE METHOD												
Hunting households	188	0.45	0.85	0.80	1.00	0.67	0.17	0.04	0.42	0.49	0.30	0.72
NO TARGETING												
All households	476	0.54	0.88	0.80	0.40	0.61	0.16	0.10	0.46	0.37	0.33	0.73

Table 2. Profiles of hunter groups defined using clustering and simple methods, with proportions of each group that had behaviour or livelihood attributes.

Target group	Group Size (number of hunters)	Total estimated biomass harvest (kg / day)	Local citizen	Uses Gun	Uses snare	offtake > 8.5 kg/day	Effort > 14 days / month	Income > $100 / month	Skilled trade	Cocoa	Mine	Palm	Petty goods trade
CLUSTER METHOD													
Non-local gun hunters	87	1216.4	0.02	1.00	0.49	0.60	0.78	0.61	0.09	0.02	0.24	0.09	0.22
Local trappers	31	611.9	0.87	0.26	1.00	0.81	0.33	0.42	0.10	0.48	0.23	0.65	0.13
Local gun-hunters	49	531.4	0.90	1.00	0.17	0.38	0.25	0.62	0.14	0.55	0.08	0.37	0.12
Non-local trappers	28	413.9	0.15	0	1.00	0.54	0.53	0.15	0.04	0.07	0.11	0.04	0.29
Occassional hunters	10	96.8	0.80	0.90	0.40	0.56	0.10	0	0.10	0.90	0.70	0.80	1.00
SIMPLE METHOD													
High-impact hunters	40	1442.3	0.45	0.70	0.68	1	0.50	0.67	0.13	0.33	0.13	0.23	0.15
NO TARGETING													
All hunters	205	2870.2	0.41	0.75	0.56	0.57	0.51	0.55	0.10	0.27	0.21	0.27	0.23

S1 Table 3. Socio-demographic attributes (mean±SD) of household groups defined using clustering and simple methods.

Household Group	n	Years residency in village[a]	Adults / household[b]	Children / household[c]	Proportion high-school educated[d]
CLUSTER METHOD					
Non-local farmers	128	10.9±7.9	2.9±1.7	3.4±2.1	0.46
Local farmers	176	19.1±14.6	3.4±2.1	3.8±1.8	0.37
Non-local hunting households	31	10.4±10.2	2.3±0.9	2.6±1.7	0.61
Merchants and salaried workers	63	15.4±13.5	3.3±1.9	3.1±1.7	0.60
Non-local miners	68	16.1±13.2	3.2±2.1	2.1±1.7	0.44
Local plantation farmers	10	11.6±5.5	2.8±1.1	2.8±1.7	0.60
SIMPLE METHOD					
hunting households	188	14.5±12.5	3.3±2.1	3.4±2.0	0.50
non-hunting households	288	15.8±13.0	3.0±1.7	3.2±1.9	0.43
NO TARGETING *(all households)*	476	15.3±12.8	3.12±1.9	3.3±1.9	0.46

[a] This variable is closely associated with citizenship which was used to define clusters, so statistical comparisons across groups were not applied.
[b] There was no significant difference between cluster method groups ($F(5,470)=2.42$, $p=0.03$) or simple method groups ($F(1,474)$,$p=0.23$).
[c] Cluster method groups differed ($F(5,470)=9.11$, $p<0.0001$). *Non-local miners* had fewer children than either *Non-local farmers* (Tukeys test, mean difference = -1.3, 95% CI -2.1--0.5, $p<0.0001$) or *Local farmers* (mean difference = -1.7, 95% CI -2.4- -0.9, $p<0.0001$). Simple method groups did not differ significantly ($F(1,474)=1.87$, $p=0.17$).
[d] Proportion of households with at least one member having high-school education was unevenly distributed among cluster method groups (Chi-squared test, n=471, $\chi 2= 15.09$, df = 5, p-value < 0.001) but not simple method groups (n=471, $\chi 2 = 2.03$, df = 1, p-value = 0.15).

S1 Table 4. Socio-demographic attributes of hunter groups defined by clustering and simple methods (mean±SD).

Hunter Group	n	Years of residency in village[a]	Age[b]	Years hunting[c]	Children[d]	Proportion married[e]	Proportion high-school educated[f]
CLUSTER METHOD							
Non-local gun-hunters	87	9.2±5.1	43.6±11.1	10.2±8.2	4.6±2.7	0.84	0.47
Local trappers	31	18.0±13.5	34.6±10.7	7.0±5.2	3.4±2.5	0.81	0.26
Local gun-hunters	49	24.1±17.0	40.0±11.2	10.2±10.0	4.6±3.9	0.92	0.23
Non-local trappers	28	8.5±8.0	42.5±10.5	7.6±7.2	4.6±3.3	0.75	0.39
Occasional hunters	10	9.2±12.8	39.3±6.4	12.5±9.1	5.5±2.6	1	0.20
SIMPLE METHOD							
High-impact hunters	40	16.6±15.7	42.4±13.3	9.7±8.0	4.1±2.6	0.88	0.30
Low-impact hunters	165	13.9±11.9	40.7±10.6	9.4±8.4	4.6±3.2	0.84	0.37
NO TARGETING *(all hunters)*	205	14.4±12.8	41.0±11.1	9.5±8.3	4.5±3.1	0.85	0.35

[a] This variable is closely associated with citizenship which was used to define clusters, so statistical comparisons across groups were not applied.
[b] Age differed significantly between cluster method groups ($F(4,194)=4.16$, $p=0.003$). *Local trappers* were younger than *Non-local gun-hunters* (Tukey Test difference in means=9.0, 95% CI 2.7-15.3, $p=0.001$). There was no significant difference between simple method groups ($F(1,197)=1.06$, $p=0.3$).
[c] There was no significant difference between cluster method groups ($F(4,200)=1.66$, $p=0.2$) or simple method groups ($F(1,203)=0.02$, $p=0.9$)
[d] There was no significant difference between cluster method groups ($F(4,199)=1.27$, $p=0.3$) or simple method groups ($F(1,202)=0.64$, $p=0.4$)
[e] There was no significant difference between cluster method groups (Pearson's Chi-squared test, n=205, $\chi2=6.26$, df=4, $p=0.2$) or simple method groups (n=205, $\chi2=0.04$, df=1, $p=0.8$).
[f] High-school educated hunters were unevenly distributed across cluster groups (Pearson's Chi-squared test, n=202, $\chi2= 10.03$, df = 4, $p=0.04$) but not simple method groups (n=202, $\chi2=0.27$, df=1, $p=0.6$).

Chapter 5. The bean method as a tool to measure sensitive behaviour

This chapter is published as the following, with minor differences in the text:

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(46 pages)

Introducing the bean method as a tool to measure sensitive behaviour

ABSTRACT

Conservationists need to measure human behaviour to guide decisions and evaluate their impact. However, activities can be misreported and reporting accuracy might change following conservation interventions, making it hard to verify any apparent changes. Techniques for asking sensitive questions are increasingly integrated into survey designs to improve data quality but some can be costly or hard for non-experts to implement. We demonstrate a straightforward, low-cost approach, the "bean method" in which respondents give anonymous answers by adding a coloured bean to a jar to denote a yes or no response. We apply the bean method to measure wildmeat hunting and trading prevalence over two years at a conservation project site in Gola Forest, Liberia, and extend the technique to accommodate questions about hunting frequency. We compare responses given using the bean method and direct questions, for groups that did and did not participate in conservation interventions. Results from the bean method corresponded to those from direct reports, giving no indication of change in question sensitivity following conservation interventions. Estimates from both methods indicate that wildmeat trading decreased in project and non-project households (from 36% to 20%), while hunting decreased in one project group (38% to 28%). Where inconsistent answers were given (2 to 6% of respondents), differences were in both directions and were most likely attributable to measurement error. The bean method was quick and straightforward to administer in a low-

literacy setting. We show it can be modified for answers of more than two categories and consider it a valuable tool that could be adapted for a wide range of conservation settings.

INTRODUCTION

To improve conservation interventions, it is essential to measure behaviour-change impacts and build an evidence base to guide decisions (Schultz, 2011). However, behaviours of interest to conservationists are often illegal, making them challenging to study (Gavin et al., 2010). One problem is social desirability bias: systematic error introduced when people inaccurately report behaviour in order to convey a more socially desirable image (Krumpal, 2013). Such bias can lead to under-reporting of sensitive activities or over-reporting of desirable behaviour (Tourangeau and Yan, 2007). It presents a particular problem for evaluating conservation impacts, since many interventions explicitly aim to alter the social desirability of behaviour, for instance through education or social marketing campaigns (Salazar et al., 2019). Consequently, data collected before and after interventions may have different degrees of misreporting, making it hard to identify genuine changes. The issue that sensitive behaviour may be misreported has led to increased use by conservationists of survey methods explicitly designed to address this (Nuno and St. John, 2015).

A growing body of research applies specialised questioning techniques to understand sensitive conservation behaviours (e.g. Fairbrass et al., 2016; Hinsley et al., 2019; Nuno and St John, 2014; St John et al., 2014, 2012; Travers et al., 2019). These techniques are designed to encourage truthful reporting by protecting anonymity of respondents and ensuring researchers cannot link behaviour directly to individuals (Nuno and St. John, 2015). Two well-known approaches are the randomised response technique (Warner, 1965) and unmatched count technique (Droitcour et al 1991), but a variety of other methods have been developed and applied in conservation settings (Nuno and St. John, 2015; St. John et al., 2010). Studies comparing estimates from specialised methods to those resulting from asking questions directly, offer insight into the performance of different approaches (Razafimanahaka et al., 2012) and provide evidence that specialised techniques can increase reporting of sensitive topics (Lensvelt-Mulders et al., 2005; Phillips et al., 2010). However, many specialised techniques are statistically inefficient, requiring large sample sizes (Hinsley et al., 2019), can be cumbersome for respondents and enumerators, and require advanced statistical approaches to analyse and interpret results. If the sensitivity of the activity under investigation is initially low, specialised techniques may unnecessarily complicate monitoring data, wasting valuable resources (Hinsley et al., 2019). Further, complex techniques can introduce new sources of error, such as whether respondents or interviewers follow instructions correctly (Davis et al., 2019; Lensvelt-Mulders et al., 2005). Nevertheless, specialised questioning methods have proven effective to understand illegal conservation activities which are otherwise challenging to measure (e.g. Nuno et al., 2013; Razafimanahaka et al., 2012). Development of straightforward, low-cost techniques would further enable conservationists to measure sensitive behaviour across a wider range of settings.

The bean method, developed by Lau et al (2011), may meet these criteria but to our knowledge, has yet to be used in conservation. The bean method employs a basic system whereby respondents report their 'yes' or 'no' answer by placing a bean (or counter) of specified colour (e.g. black=yes, red=no) into a container which already contains a known number beans of those colours. Interviewers do not observe participants moving beans but count the beans after each day or survey block, to obtain group-level estimates. Investigating sexual behaviour, Lau et al (2011) found the bean method gave prevalence estimates up to 10% greater than direct reports. The method has limitations, for example it provides only group-level estimates, so cannot be used to investigate drivers of individuals' behaviour, and its original formulation allows only a limited number of binary (e.g. yes-no) questions to be asked. However, it is straightforward and cheap to administer, raw results are easy to interpret, and it can be appended to questionnaire-based surveys to generate insight into social desirability bias without significantly increasing data collection costs. Materials can be locally sourced, making it particularly appropriate for settings where complex approaches are likely to be viewed with suspicion. The bean method has received little attention since its development (but see Cerri et al., 2017), but similar approaches have been successfully used to measure sensitive health behaviours in low-literacy populations (Lowndes et al 2012) .

Here we apply the bean method alongside direct questions to measure wildmeat hunting and trading at a conservation project site in Gola Forest, Liberia. Wildlife is hunted across Liberia providing an income source for hunters, traders who transport dried meat to urban markets, and marketeers who sell to consumers (Jones et al., 2019). It is widely consumed, particularly in rural areas where it represents a relatively affordable protein source (Ordaz-Németh et al., 2017). National laws prohibit unlicensed hunting, hunting in protected areas and killing of protected species (National Wildlife Act, 2016), but are not widely enforced. Hunting-reduction interventions implemented by conservation projects could be expected to increase under-reporting of hunting and trading. To explore this, we compare estimates from the bean method and direct questions, before and after implementation of hunting-reduction interventions, and for groups that did and did not receive interventions. We extend the method to measure frequency of activities by allowing answers in more than two categories. This study focuses on the application of the bean method as a tool to measure behaviour, and evaluation of the impacts of interventions will be presented elsewhere.

METHODS

Study site

The study was conducted at the site of an ongoing conservation project, GolaMA, implemented by the Society for Conservation of Nature in Liberia and the Royal Society for the Protection of Birds. GolaMA aims to reduce wildmeat hunting and trading in community forests through community-based management, while improving income from conservation-friendly livelihoods. The project works with two neighbouring administrative units, or clans (henceforth 'group 1' and 'group 2'), supporting each to establish their own community-managed forest. The two clans share similar socio-demographic profiles, in terms of poverty metrics and age structure, with subsistence rice farming being the predominant livelihood activity of both clans (Supporting Information). At the first round of data collection, project interventions specifically targeting wildmeat hunting and trading had not been implemented and project activities had focussed on socio-economic surveys, resource management workshops, and pilot phases of livelihood support work. By the second round of data collection, livelihood support programmes had been implemented across all households, consisting of training to increase agricultural yields, introduction of bee-keeping, small-loans schemes providing access to low-interest credit, and adult literacy classes. There had also been initial work supporting small-scale miners to improve revenues. Participants in all livelihood programmes made formal agreements to refrain from commercial wildmeat hunting or trading. Workshops and meetings were conducted to inform people about existing hunting regulations and conservation management. All interventions were applied across the two clans that participated in GolaMA, with minor differences in timing of implementation. During the study, non-project conservation activities took place, relating to boundary demarcation of the Gola Forest National Park, which borders the project site. These included increased ranger patrols and confiscation of wildmeat at a roadblock along the road to Monrovia. Small-scale mining is prohibited within the park but mining in community forest is not regulated by park rangers. By contrast, wildmeat could be confiscated by rangers regardless of where hunting occurred.

Wildmeat hunting and trading were socially acceptable activities about which people spoke freely (Jones et al., 2019). Nevertheless, some degree of social desirability bias could be expected given many hunters (45%, n=130) and traders (71%, n=36) reported incurring penalties in the past (Jones et al., 2019a). Small-scale mining was openly practised but often without legally required licenses.

Survey methods

The bean method was applied alongside direct questions in a single questionnaire administered to households during face-to-face interviews. The questionnaire was administered during two time periods: the initial phases of GolaMA (February to July 2017), and the projects' final year (February to March 2019). The sample in each of the two survey periods comprised a complete census of all households in villages belonging to two clans that participated in GolaMA (group 1 and group 2), and in three villages in neighbouring, non-participating clans (non-project group). The same households were targeted in each survey period. The two clans participating in the golaMA project are considered separately as group 1 (nine villages) and group 2 (six villages) to give results which are informative for project managers, and to account for differing livelihood patterns between clans (see Supporting Information).

The questionnaire measured prevalence for behaviours targeted by conservation interventions (wildmeat hunting and trading) which could be expected to decrease in prevalence and increase in sensitivity due to project implementation. A non-target behaviour (small-scale mining) was also measured, providing a comparison with an activity supported by the project. Small-scale mining was not expected to become more sensitive or less prevalent during the study. In contrast to hunting, project activities aimed to support, not restrict, mining activities (see Supporting Information), and law enforcement by park rangers related only to mining within the protected area which was unlikely to affect miners in our study as these operated almost entirely within community forests. Frequency of hunting and wildmeat selling were measured using an extension of the bean method (see below). Prevalence and frequency estimates obtained from the bean method were compared to those obtained via direct questions. Further, inconsistency of responses was evaluated to assess minimum levels of misreporting.

The questionnaire was administered to the most senior household member present and had five sections (Supporting Information). Starting and ending times of interviews were recorded. Section one consisted of basic socio-demographic questions. In section two, respondents were directly asked, for each of 12 livelihood activities, whether any household member had engaged in the activity over the past six months. Activities included hunting, wildmeat trading and mining alongside other common activities such as farming, charcoal production and fishing. In section three, the bean method (see below) was applied to ask if any household member had engaged in hunting, wildmeat trading and mining during the same six-month period. In section four, a modified form of the bean method (see below) was applied to ask two questions: the number of days any household member had been hunting during the previous week, and number of carcasses sold in the previous week up to a maximum of ten. In the final section, respondents were directly asked the same two questions about frequency of hunting and carcasses sold. For frequency questions, an important consideration was that counting and moving beans would become obvious for large numeric responses. A week timeframe was therefore chosen to limit possible hunting days to seven, and carcass sales were capped at ten. Respondents may be less likely to recall activities over longer time periods, and weekly religious observances provided temporal reference points.

Free, prior and informed consent was given verbally by all respondents. Respondents were informed that the study sought to understand livelihood activities, the answers they provided would be confidential, and results of the study would be published. Specific permission to conduct the survey in each village was obtained from clan and village authorities. Ethical approval for the study was given by Royal Holloway University of London ethics committee.

The bean method

The bean method was applied as follows. Respondents were asked to provide ‘yes’ or ‘no’ answers by taking a bean of a specified colour/type from a ‘selection container’ and placing it in an ‘answer container’ (Fig. 1). Prior to asking each question, the interviewer demonstrated which type of bean signified a ‘no’ answer, which would signify ‘yes’, and checked the respondent understood by asking them to demonstrate their choice of bean for a dummy question about a non-sensitive topic. The interviewer then asked the sensitive question, turning around so they could not observe the respondent’s bean choice. Three questions were asked with this method, with a different type of bean signifying ‘yes’ for each question, and the same type of bean signifying ‘no’ for any question. One ‘answer container’ and one ‘selection container’ were used for these three questions.

Locally sourced containers and beans were used (Fig. 1). The ‘selection container’ was a large (approx. 1 litre) plastic cup, inside which we placed an opaque plastic bag half-filled with an even mixture of five different types of bean. The cup had a broad opening allowing respondents to easily see inside to select beans, and the plastic bag allowed them to further conceal their selection by using it to completely cover their hand. The ‘answer container’ was a clear plastic jar (approx. 1 litre) with a label around the centre and filled approximately one-third of the way with an even mix of the five different types of beans. Respondents could clearly see there were many beans in the jar already, and the label concealed the area in which a respondent’s bean landed. Five types of bean were used (Fig. 1): red kidney beans (type “a”) were used to denote a ‘no’ answer to any question; square white beans (type “b”) denoted ‘yes’ to the first question (‘has anyone in your household engaged in wildmeat trade in the past 6 months’); flat mottled beans (type “d”) denoted ‘yes’ to the second question (‘has anyone...engaged in hunting’); and pink and white beans (type “e”) denoted ‘yes’ to the third question (‘has anyone...engaged in mining’). The fifth ‘bean’ was a dark brown seed (type “c”) of a similar size and was included to indicate method comprehension; the quantity of this bean in both containers should remain constant as it was not associated with answering questions. At the start of each day, the answer container held 50 of each type of bean. The selection container had approximately twice this number.

Surveys were conducted by two teams of one or two trained interviewers, who were local residents in one of the study villages. Where possible at least one female interviewer was on each team. Beans were counted by each survey team at the end of each day, and no more than 35 households were surveyed in a day to limit potential mistakes during counting. For small villages, a survey-day included all households in the village (range = one to 30 households). In large villages, households were surveyed over multiple days, or by more than one team. To ensure respondent protection, we do not report data at the village level (St.John et al., 2016).

The modified bean method for more than two categories

We adapted the bean method described above to obtain estimates for frequency of hunting and selling wildmeat. A separate answer container was used for frequency questions with the same appearance as the yes-no answer container. The same selection container was used for both yes-no and frequency questions. Respondents were instructed to answer frequency questions by moving a number of beans into the answer container, with a separate colour denoting an answer of 0. For the first question, ‘how many days has anyone in your household been hunting in the past week?’, 0 answers were denoted by bean type “a” (Fig 1A) and the number of days was indicated by bean type “b”. For the second question, ‘how many carcasses has anyone in your household sold in the past week?’, 0 answers were denoted by bean type “c”, and number of carcasses denoted by bean type “d”. To limit the amount of counting for high answers, respondents were instructed to move 10 beans for answers of 10 or greater. The bean method was modified during the first survey period to distinguish between zero answers given to each frequency question. In the initial version, administered in 2017 in five villages, the same colour of bean was used to denote zero answers for both frequency questions. This was then changed so zero answers to each frequency question were denoted by different colours. Proportion of households engaged in hunting or meat selling in the previous week could therefore not be calculated from the bean method in 2017 for the non-project group and group 1.

Evaluation of methods

Prevalence of hunting, trading and mining across households was estimated in each survey period as proportion of respondents answering ‘yes’ to direct and bean method questions respectively. Prevalence was calculated separately for each clan (“group 1” and “group 2”) that participated in the GolaMA project, and for the non-project group.

Frequency of hunting and wildmeat selling was measured as number of days any household member had been hunting in the previous week, and number of carcasses sold by any household member in the previous week. Average number of days hunting and carcasses sold was calculated across all households, and among only households that had engaged in the activity in the previous week. The proportion of households who engaged in either activity in the previous week was the proportion of non-zero answers.

For all estimates, 95% confidence intervals were calculated as S.E.*1.96. However, for bean method responses to frequency questions, individuals’ answers are unknown. Therefore, mean response for each survey-day was used to calculate standard errors, and the sample size was taken to be number of survey-days. This approach fails to account for variable numbers of respondents in each survey-day, so provides only rough approximation.

To evaluate inconsistency between answers obtained through the bean method and direct questions, the difference in ‘yes’ answers from each method was calculated for each survey-day. For frequency questions, we calculated difference in mean answer per household for each survey-day. Direct responses for frequency of carcass-selling frequency were capped at ten carcasses per respondent for comparison with the bean method.

RESULTS

There were 480 households in total in the study area during the first round of data collection (2017); 475 participated fully, one household abstained and four gave incomplete answers. During the second round (2019), there were 524 households all giving complete answers. The same households were targeted in both rounds of data collection, so differences in sample sizes between years reflect socio-demographic processes (e.g. migration, marriage). Sample sizes were similar for each of the two clans that participated in the GolaMA project (group 1 and group 2) and the households from non-project villages (non-project group). In 2017, number of respondents (households) in group 1, group 2 and the non-project group were 201, 136 and 143 in 2017, and 181, 168 and 175 in 2019. Average respondent age was 40.7 SD=14.5 (2017) and 41.3 SD=14.0 (2019), with 49% and 48% male respondents. Household sizes, respondent ages, gender and marital status were similar across groups and survey periods (Supporting

Information). Number of respondents per survey-day ranged from one to 31 in 2017 (mean=15.0) and two to 34 in 2019 (mean=12.8). Lower limits reflect village sizes. The questionnaire took an average of 9.5 minutes to administer (n=975, SD=3.8).

Prevalence of hunting, wildmeat trading and mining

The proportion of households reporting hunting via direct questions did not change from 2017 to 2019 in the non-project group (Fig. 2), increased slightly in group 1 and decreased in group 2. Differences were not statistically significant (Chi-square tests, df=1, p>0.05; Supporting Information, Appendix S7). Across all groups hunting was reported by 39%[35-44%, 95%CI] of households in 2017, and 38%[34-42%] in 2019. Trading prevalence was lower in 2019 than 2017 in all groups (X-squared = 29.0, df=1, p<0.0001; Supporting Information Appendix S7), decreasing from 36%[31-40%] of all households in 2017 to 20%[17-24%] in 2019. Mining prevalence changed little overall excepting an increase in group 1, from 23%[17-28%] to 31%[24-38%] (Supporting Information Appendix S7).

Responses from the bean method indicated similar prevalence and patterns as direct questions (Fig. 2; Supporting Information, Appendix S7). Differences between the methods were inconsistent, varying across groups and years. For instance, in 2017 hunting prevalence appeared lower with the bean method than direct questions in group 1 but not group 2, whereas in 2019 estimates were similar or lower for all groups. Methods produced similar mining estimates, excepting group 2 which showed higher bean method estimates in 2017, then lower in 2019. Frequency of the bean type added to check question comprehension stayed constant for all survey-days, indicating it was not erroneously selected by respondents.

Frequency of hunting and wildmeat selling

Mean days spent hunting during the previous week decreased in group 2 from 1.03[0.73-1.33 95%CI] in 2017 to 0.54[0.36-0.71] in 2019, but changed little in other groups (Fig. 3). Proportion of households that hunted in the previous week followed the same pattern (Supporting Information). Among households that hunted in the previous week, mean days spent hunting decreased slightly across all groups, from 2.79[2.54-3.04] in 2017 to 2.34[2.13-2.54] in 2019 (Supporting Information). Mean carcasses sold per household decreased in all groups from 1.63[1.25-2.01] to 0.76[0.59-0.93], with the greatest change seen in group 2 (Fig. 3). The proportion of households selling wildmeat in the previous week decreased only in group 2 (from 37%[29-45%] to 17%[11-22%]; Supporting Information). Among households selling wildmeat in the previous week, average number of carcasses sold was higher in 2017 (5.73[5.02-6.45]) than 2019 (3.13[2.78-3.48]) with the largest difference in group 2 (Supporting Information).

Reported number of days' hunting and carcasses sold in the previous week were similar under the bean method as direct questions. The small differences in reporting between methods showed no consistent pattern across survey groups and years (Fig. 3). This was also the case for the proportion of households that had hunted or sold meat in the previous week, and average number of days' hunting or carcasses sold per household that had hunted or traded (Supporting Information).

Inconsistency between answers to direct questions and the bean method

A small percentage of respondents gave inconsistent answers to the same question asked directly or with the bean method (2 to 6%; Table 1). Inconsistency occurred in both directions, was similar across questions and slightly higher in 2019 than 2017 for all questions. The highest proportion of inconsistent answers was 12% (group 2, 2017; Table 1). Responses to questions about the number of days' hunting and carcasses sold in the previous week showed slight inconsistency that followed the same pattern as yes-no questions (Supporting Information). Survey-day differences ranged from 0 to 1.25 hunting days/respondent (2017 mean=0.08 SD=0.16, n=32 survey-days; 2019 mean=0.07 SD=0.23, n=41 survey-days) and 0 to 3.80 carcasses/respondent (2017 mean=0.23 SD=0.72, 2019 mean=0.03 SD=0.12).

DISCUSSION

This study explored the potential of the bean method as a tool to measure sensitive behaviour. Results showed no consistent difference between answers given anonymously through the bean method or directly, either before or after conservation interventions. This suggested that sensitivity of hunting and trading behaviour remained low, or that under-reporting was similar across both methods. Both methods indicated a decrease in wildmeat trading across all households, while hunting changed little overall. As with any approach, accuracy of either direct questions or the bean method remains unknown and both face several sources of measurement error. However, our findings highlight useful properties of the bean method: it was low-cost, quick and straightforward to implement, appropriate for low-literacy populations, materials could be locally sourced, and raw results could be immediately interpreted without statistical manipulation.

Bean method results agreed closely with those from direct questions, for all groups and survey periods. This could indicate that mistrust and associated under-reporting remained undetected, or alternatively, that questions were not sensitive. We believe the latter is likely for several reasons. First, previous work found hunters and traders freely discussed their activities despite having experienced wildmeat confiscation (Jones et al., 2019). Second, motivation to under-report behaviour might have remained low: the conservation project did not implement penalties and questions applied to all household members, not individuals, minimising personal risks. Finally, interviewers were local citizens, potentially reducing respondents' suspicion or promoting perceptions that falsehoods would be detected (Weinreb, 2006). Given this apparently low sensitivity of behaviours in our study, a question remains whether the bean method promotes truthful reporting of sensitive topics. Previous results suggest it can be effective in some cases: Lau *et al.* (2011) found reporting of risky sexual behaviours increased with the bean method in four out of five surveys, relative to direct questions, while Cerri *et al.* (2017) found higher reporting for two out of four illegal fishing activities. Neither study found reporting to be lower with the bean method.

Application of more than one questioning format can generate insight into data quality (Anglewicz et al., 2013), and the bean method was useful in this regard. Responses were largely consistent between methods and misreporting showed no systematic patterns, suggesting inconsistent answers represented background measurement error which may be unrelated to question sensitivity and could affect either method. Self-reported information can be influenced by factors such as contextual cues which alter how questions are interpreted, the cognitive process of recalling information, interviewer-respondent dynamics, the previous exposure of respondents to surveys and interviewer experience (Burton and Blair, 1991; Schwarz, 2007; West and Blom, 2017). In our study, direct questions were situated within a list of livelihood activities while bean method questions were not, potentially influencing question interpretation. The process of counting beans could positively affect accuracy of answers to frequency questions. For example, the visual prompt may reduce recall error (Burton and Blair, 1991) or people's tendency to round answers to values ending in zero or five (Vaske et al., 2006). More respondents gave consistent answers in the second survey than the first, and the same households were targeted in each survey round. This is consistent with findings that response reliability is highest where respondents have previously participated in surveys, and among interviewers with previous survey experience (Wolter and Preisendörfer, 2013).

The bean method could be a useful addition to the range of specialised questioning techniques used in conservation. Other straightforward approaches, such as the ballot box method, can be unsuitable in low-literacy settings (Bova et al., 2018), or may require extensive pre-testing, as for the unmatched count technique (Hinsley et al., 2019). Complex approaches, such as the randomised response technique, can be time-consuming for interviewers and respondents to comprehend (Davis et al., 2019), and can create suspicion among respondents (Bova et al., 2018), whereas we found the bean method was well-received, quick to administer and interviewers required little additional training. Unlike probability-based approaches, bean method results can be immediately interpreted which is useful for community-based management (Turreira-García et al., 2018). Relative to the unmatched count technique or the randomised response technique, the bean method may be better suited for small sample sizes or behaviours with low prevalence (Hinsley et al., 2019; Lensvelt-Mulders et al., 2005). However, unlike these approaches the bean method cannot be used to explore individual-scale drivers. Additionally, respondent error or counting mistakes have not been evaluated, but these could inflate estimates of low-prevalence behaviours.

Limitations of the bean method include that only a restricted number of questions can be asked and only group-level estimates are generated. We found that answers of more than two categories can be accommodated but the range of values is constrained since counting large numbers of beans could become conspicuous and demanding. There also remains the technically challenging issue of estimating confidence intervals for frequency questions. Importantly, care is needed to ensure respondents are fully protected (St.John et al., 2016). For instance, a small village in our study had only one respondent whose answer was identifiable. Similarly, if all individuals in a survey-day give identical responses then answers are not anonymous. Ensuring a minimum sample size is reached before beans are counted, and avoiding generating village-level results, would help address respondent protection issues. Further work could be usefully directed at quantifying sources of error, improving methods for estimating uncertainty and assessing how details of survey administration affect results. For instance, having given a direct answer, respondents may give the same answer with the bean method in order to maintain consistency, whether or not it was truthful. When we asked respondents with only one method (either directly of the bean method), behaviour was reported at similar levels (Supporting Information), but larger sample sizes are needed to verify this pattern.

Our study did not aim to assess effectiveness of hunting-reduction efforts. However, insights from the results are worth highlighting, as both methods indicated wildmeat trading decreased across project and non-project households. Reports of local residents suggested law enforcement at a roadblock prompted some traders to abandon their activities. Jones et al., (2019a) found a high proportion of traders from project and non-project villages relied on transporting meat through this roadblock, and cited meat confiscation as a motive for reducing trading activities. Hunters, meanwhile, faced lower financial losses from confiscations and often sold meat to non-local traders who utilised alternative transport routes (Jones et al., 2019), possibly explaining why hunting showed little decrease. Notably, villages closest to the roadblock reported larger declines in both trading and hunting. Bean method results were useful as additional information to help managers assess the likelihood that these trends were genuine rather than being due to under-reporting (A. Gardner, *pers. comm*).

Our case-study illustrates that the bean method is a practical tool which could be valuable for measuring conservation behaviours. Although questions in our study were not apparently sensitive, the method provided useful insight into response reliability by revealing consistency of answers under alternative questioning modes, and helped managers to interpret survey results. More work is needed to evaluate its performance for measuring sensitive topics. However, the bean method has practical advantages of being low-cost and straightforward to implement and we consider there is scope to adapt and extend the method to a wide variety of contexts.

Supporting Information

Background information about the study site and GolaMA project (Appendix S1), socio-demographic descriptions of households (Appendix S2), comparisons between responses to frequency questions given using the modified bean method and direct questions (Appendix S3), results of frequency questions (Appendix S4), results from separate administration of the bean method and direct questions (Appendix S5), the survey questionnaire (Appendix S6) and chi-square test results to compare proportions of hunting and trading households at the start and end of project surveys (Appendix S7) are available online.

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TABLES

Table 1. Consistency of answers to yes-no questions when respondents were asked directly and through the bean method: the percentage of consistent responses (Same answers); the percentage of people reporting ‘yes’ when asked directly but ‘no’ to the bean method (Direct question high); and the percentage of people reporting ‘no’ when asked directly and ‘yes’ to the bean method (Bean method high).

	Group 1		Group 2		Non-project group		All groups	
	2017	2019	2017	2019	2017	2019	2017	2019
n households	201	181	136	168	143	175	480	524
Hunting								
Same answers	94%	96%	92%	96%	97%	99%	94%	97%
Bean method high	1%	1%	4%	2%	0%	1%	2%	1%
Direct question high	5%	3%	4%	2%	3%	1%	4%	2%
Trading								
Same answers	97%	98%	88%	98%	91%	97%	92%	98%
Bean method high	0%	1%	8%	0%	6%	1%	4%	1%
Direct question high	3%	1%	4%	2%	3%	2%	4%	1%
Mining								
Same answers	98%	98%	95%	95%	96%	99%	96%	98%
Bean method high	1%	1%	4%	1%	1%	0%	2%	0%
Direct question high	1%	1%	1%	4%	3%	1%	2%	2%

FIGURES WITH LEGENDS

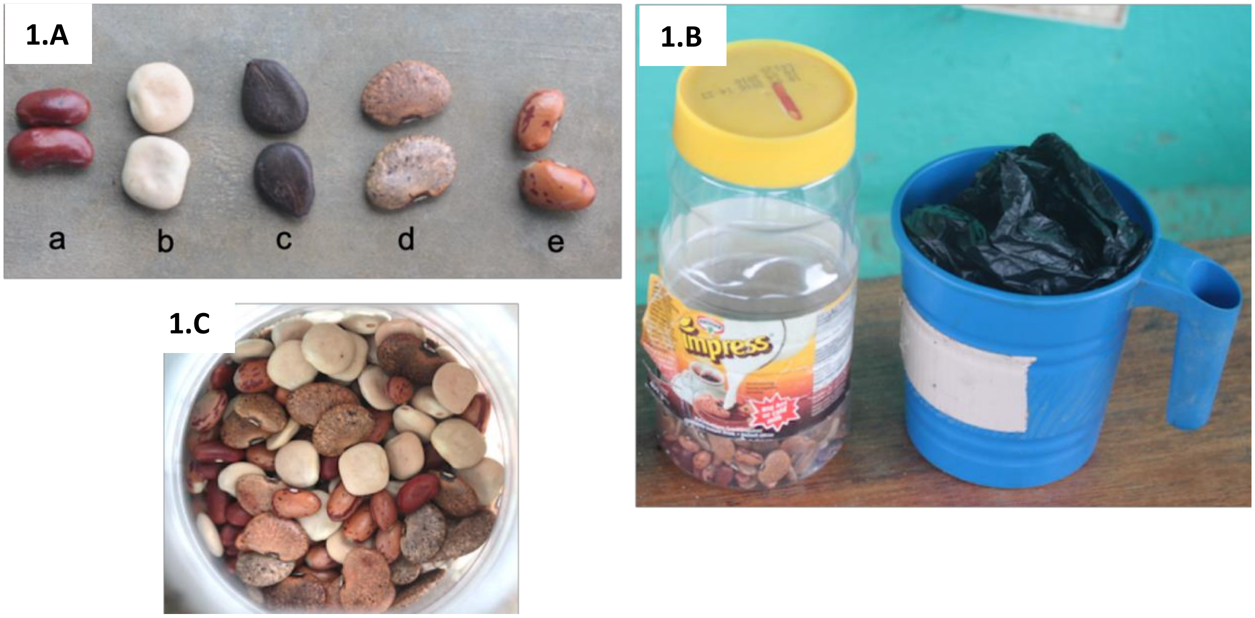

Figure 1. Locally sourced materials used to administer the bean method. 1.A. bean types used to indicate answers: a = no to any question, b = yes to question 1, c does not indicate any answer and is included to check for errors in how well instructions are followed, d = yes to question 2, e = yes to question 3. 1.B. Answer container (left) and selection container (right). Respondents selected their answer from a mixture of beans inside a plastic bag in the selection container. The bag provided additional privacy from onlookers. 1.C. Appearance inside an answer container with a mixture of four bean types.

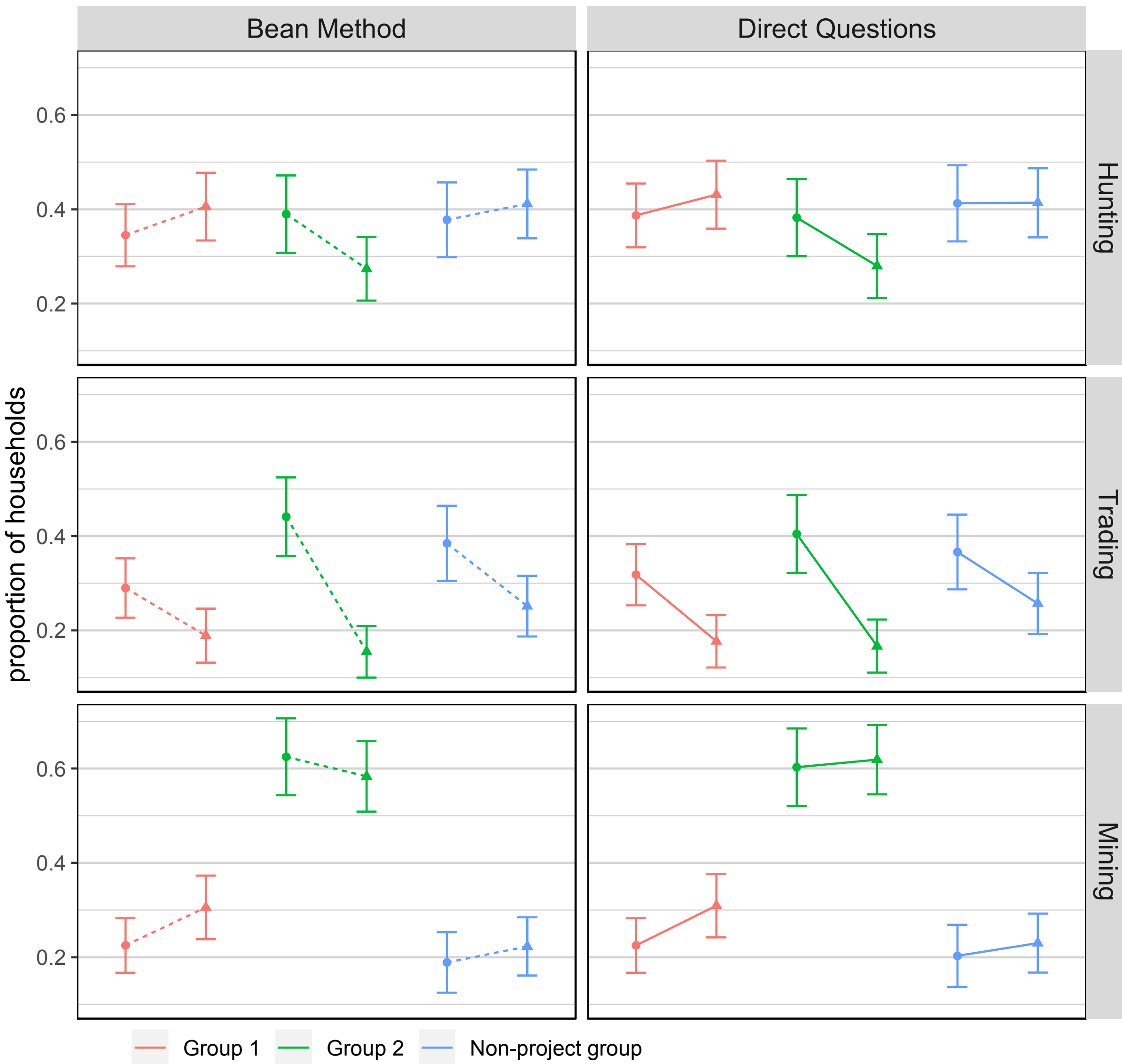

Figure 2. Prevalence of hunting, trading and small-scale mining across households at the start of a conservation project (squares, n=480) and after two years implementation (triangles, n=524). Values were obtained from the bean method (dashed lines) and direct questions (solid lines), from a complete census of two groups that participated in the project (group 1: red, 9 villages, n_{2017}=201, n_{2019}=181; group 2: green, 6 villages, n_{2017}=136, n_{2019}=168) and a non-project group

where conservation activities did not take place (blue, 3 villages, n_{2017}=143, n_{2019}=175). 95% confidence intervals are shown.

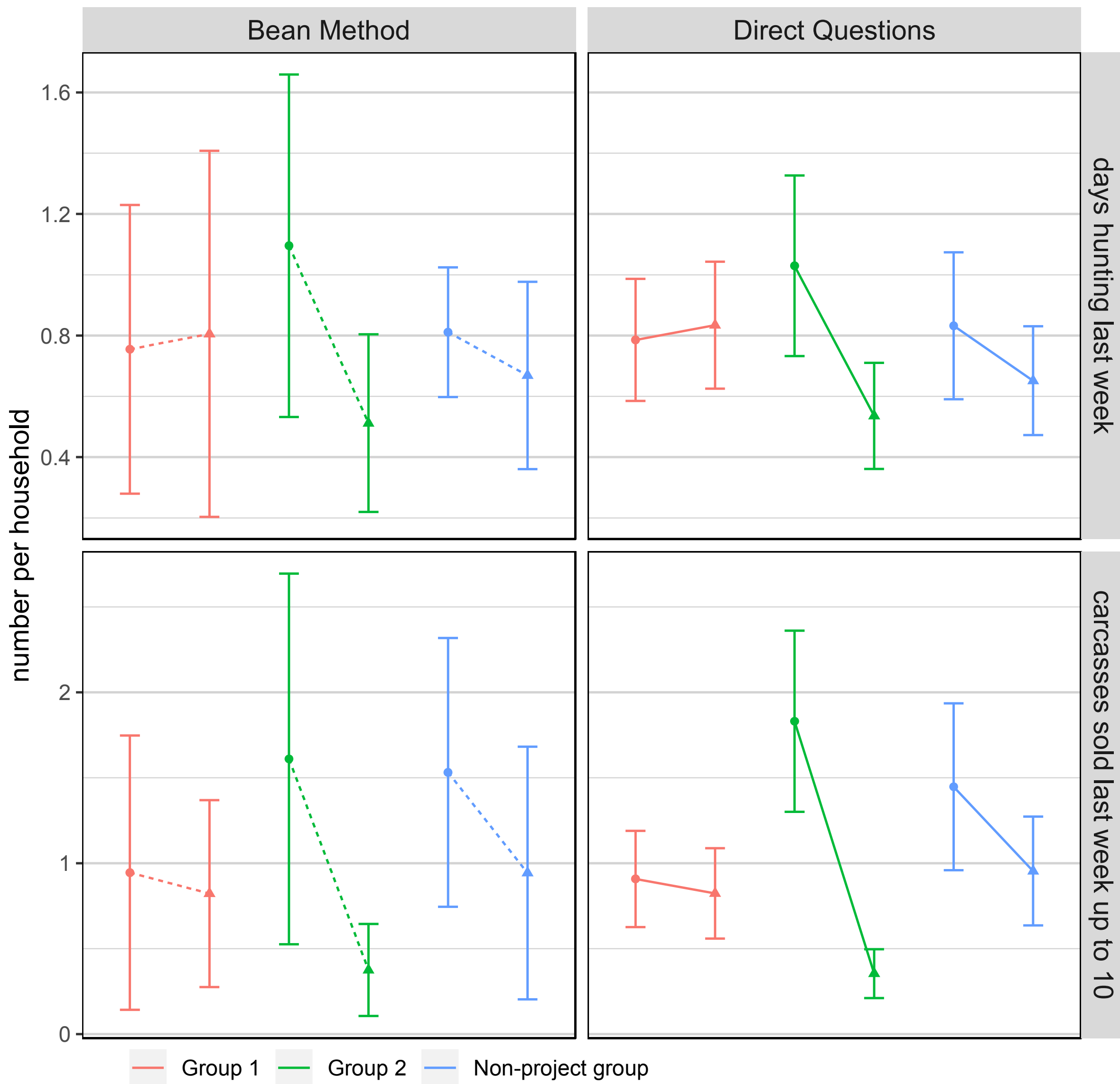

Figure 3. Frequency of hunting and sale of wildmeat carcasses across households at the start of a conservation project (squares, n=480) and after two years implementation (triangles, n=524). Values were obtained from direct questions (solid lines) and the modified bean method (dashed lines), from a complete census of two groups that participated in the project (group 1

red, 9 villages, n_{2017}=201, n_{2019}=181; group 2 green, 6 villages, n_{2017}=136, n_{2019}=168) and a non-project group where conservation activities did not take place (blue, 3 villages, n_{2017}=143, n_{2019}=175). Values for carcasses sold are capped at ten per respondent for both methods. Bars indicate 95% confidence intervals, approximated for the bean method as 1.96 * standard error of mean per household values from each survey-day.

Appendix 2 Socio-demographic description of households in the study

Households from two clans that participated in the GolaMA project (“group 1” and “group 2”), and from neighbouring clans which did not participate (“non-project group”), showed similar socio-demographic characteristics in terms of the household size, how long household heads had resided in the village, and respondents age, gender and marital status (Table 1).

Table 1. Socio-demographic descriptions of households surveyed in 2017 and re-surveyed in 2019

year	group	n house-holds	villages	respondent age (mean, SD)	proportion male respondents	proportion married respondents	years residency in village (mean, SD)	adults in household (mean, SD)	children (under 16 years) in household (mean, SD)
2017	non-project	143	3	41.4 (15.7)	0.41	0.85	17.1 (13.2)	3.1 (1.8)	3.2 (1.9)
	group 1	201	9	40.7 (14.6)	0.60	0.90	15.6 (13.6)	3.0 (2.0)	3.7 (2.0)
	group 2	136	6	40.0 (13.11)	0.42	0.78	13.2 (11.5)	3.3 (1.8)	2.8 (1.8)
2019	non-project	175	3	42.7 (14.6)	0.42	0.84	13.9 (8.7)	3.4 (1.9)	3.3 (2.3)
	group 1	181	8	41.1 (13.1)	0.52	0.92	13.0 (7.9)	3.6 (1.9)	3.0 (2.2)
	group 2	168	6	40.0 (14.4)	0.49	0.76	15.0 (12.8)	3.6 (2.2)	2.4 (1.7)

Household livelihood activities

Respondents were asked which activity was most important in their household for ‘bringing food to the home’. This question was intended to capture livelihood activities which include food production activities as well as income-generating activities which enable food to be purchased. Predominant activities for group 1 and the non-project households related to subsistence agriculture, including farming of staple crops such as rice and cassava and cultivation of gardens for non-staple foods such as vegetables and beans (Table 2; note that respondents frequently cited more than one activity). For group 2, subsistence farming activities were less prevalent relative to mining, especially in the first survey period (2017), although the second survey period (2019) saw an increase in garden cultivation as a source of food. This increase, from 4% to 46%, may have related to the agricultural support activities implemented by the GolaMA project, which included provision of peanuts and beans for village-groups to cultivate, although the same pattern was not observed in group 1.

Households were asked about livelihood activities which their household had been doing in the previous six months, from a list of twelve activities (Table 3). Agriculture (farming staple crops, and cultivating non-staple crops) was prevalent across all groups, but less so among households in group 2. Small business enterprises, which included buying and selling of petty goods or foodstuffs, as well as selling home-made goods such as soap or bread, were also a relatively common income source, practiced by 60 to 90% of households (Table 3). The high proportion of households who had engaged in fishing activities likely reflects the timing of the surveys, which coincided with the dry season when water levels are low enough for fishing with home-made nets. Group 1 showed a higher proportion of households engaged in cocoa and palm-oil cultivation than either group 2 or the non-project group, but relatively low proportion of households with members who had formal employment. Local employment types included teaching, health-care workers and GolaMA project staff.

Table 2 Activities reported to be the ‘main activities bringing food into the home’ for the two clans that participated in the GolaMA project (“group 1” and “group 2”) and non-project households (“Non-project Group”). Values are percentage of households that cited the activity, (several households cited more than one main). Sample sizes are presented in Table 1.

	Group 1		Group 2		Non-project Group	
	2017	**2019**	**2017**	**2019**	**2017**	**2019**
Farming (staple crops)[a]	93%	92%	37%	52%	80%	88%
Hunting	34%	14%	19%	14%	32%	9%
Mining	17%	4%	43%	42%	8%	12%
Garden (non-staple crops)[b]	1%	12%	4%	46%	11%	6%
Small business	9%	3%	23%	13%	12%	4%
Employment	1%	1%	11%	2%	1%	1%
Other trades[c]	2%	2%	0	1%	1%	1%
Teacher	0	1%	0	2%	3%	1%
Motorbike rider	0	0	2%	3%	0	1%
Wildmeat trade	1%	0	3%	1%	1%	0
Palm oil	0	0	0	0	5%	0
Other[d]	1%	0	1%	0	0	0
Fishing	0	0	2%	0	0	0
Charcoal	0	0	1%	0	0	0
Cocoa	0	0	0	1%	0	0

[a] Farming refers to plots used to grow the staple crop, most commonly rice, although it is often inter-sown with other crops).

[b] Gardening refers to cultivation of non-staple crops, often planted on old rice fields.

[c] Other trades were masoner, carpenter and blacksmith

[d] Other activities were pastor and pit-sawyer

Table 3 Livelihood activities carried out by any household member in previous six months, percentage of households in each survey group. Sample sizes are presented in Table S1.

	Group 1		Group 2		Non-project Group	
	2017	**2019**	**2017**	**2019**	**2017**	**2019**
Garden (non-staple crops)	96%	97%	77%	80%	89%	91%
Farm (staple crops)	95%	99%	52%	61%	85%	94%
Small Business	67%	83%	83%	78%	72%	87%
Fishing	70%	77%	43%	51%	66%	78%
Cocoa plantation	74%	79%	15%	16%	39%	31%
Hunting	39%	43%	38%	28%	41%	41%
Palm-cutting[a]	48%	46%	21%	20%	39%	43%
Mining	23%	31%	60%	62%	20%	23%
Wildmeat trading	32%	18%	40%	17%	37%	26%
Charcoal	16%	1%	26%	21%	7%	9%
Employment	3%	1%	19%	15%	11%	15%
Cookshop business[b]	3%	4%	3%	12%	9%	4%

[a] Palm-cutting refers to extracting palm fruits from plantations or wild-sown palms, either as the owner of a plantation, or as a hired labourer.

[b] Preparing and selling cooked food by the bowl.

Appendix S3

Table 1. Differences between responses to a question about hunting frequency (days spent hunting during the previous week), asked using the modified bean method and direct questions

year	project group	n survey-days	respondents / survey-day (mean, range)	total reported days hunting / survey-day (mean, range)	average discrepancy / respondent (mean, SD)	average discrepancy /respondent (maximum)	discrepancy as proportion of survey-day total (mean, SD)	discrepancy as proportion of survey-day total (maximum)
2017	non-project	8	17.9 (9-27)	14.7 (8-25)	0.02 (0.05)	0.11	0.01 (0.02)	0.06
	group 1	12	16.7 (1-31)	12.7 (0-36)	0.04 (0.06)	0.17	0.02 (0.03)	0.11
	group 2	12	11.3 (2-22)	12.0 (0-27)	0.15 (0.24)	0.60	0.04 (0.06)	0.17
2019	non-project	9	19.4 (13-34)	12.8 (6-22)	0.02 (0.03)	0.07	0.01 (0.02)	0.06
	group 1	17	10.6 (2-26)	8.7 (0-31)	0.11 (0.33)	1.25	0.02 (0.07)	0.28
	group 2	15	11.2 (3-19)	5.9 (0-13)	0.06 (0.15)	0.60	0.01 (0.02)	0.08
2017	**all**	**32**	**15.0 (1-31)**	**13.0 (0-36)**	**0.08 (0.16)**	**0.60**	**0.03 (0.05)**	**0.17**
2019	**all**	**41**	**12.8 (2-34)**	**8.6 (0-31)**	**0.07 (0.23)**	**1.25**	**0.02 (0.05)**	**0.28**

Table 2. Differences between responses to a question about wildmeat selling (carcasses sold in the previous week), asked using the modified bean method and direct questions, with responses capped at 10 per respondent (see below for details).

year	project group	total reported carcasses sold / survey-day (mean, range)	average discrepancy / respondent (mean, SD)	average discrepancy / respondent (maximum)	discrepancy as proportion of survey-day total (mean, SD)	discrepancy as proportion of survey-day total (maximum)
2017	non-project	26.6 (1-60)	0.08 (0.13)	0.38	0.03 (0.05)	0.13
	group 1	15.3 (0-56)	0.06 (0.16)	0.56	0.02 (0.04)	0.15
	group 2	19.5 (0-54)	0.51 (1.13)	3.80	0.10 (0.19)	0.63
2019	non-project	18.4 (3-54)	0.01 (0.03)	0.08	0.00 (0.01)	0.02
	group 1	8.7 (0-35)	0.06 (0.18)	0.67	0.01 (0.02)	0.07
	group 2	4.1 (0-11)	0.01 (0.03)	0.09	0.00 (0.01)	0.03
2017	**all**	**19.7 (0-60)**	**0.23 (0.72)**	**3.80**	**0.05 (0.13)**	**0.63**
2019	**all**	**9.2 (0-54)**	**0.03 (0.12)**	**0.67**	**0.01 (0.01)**	**0.07**

Modified bean method for asking frequency questions about wildmeat trading: the upper limit of ten carcasses per respondent

The number of carcasses sold in the previous week was capped at ten for responses given using the modified bean method. This was to limit the number of beans respondents were asked to transfer, since counting large numbers could become conspicuous or demanding. Previous work had shown that occassionally traders sold large volumes of meat in a single transaction (Jones et al., 2019), which would have been impractical to measure using the bean method. The direct question responses were therefore capped at ten carcasses in order to make a relevant comparison with the bean method. In 2017, 14 responses out of a total of 475, exceeded 10 carcasses and were capped for comparison with bean method responses, and in 2019, this value was 4 out of 524 (Table 3).

Table 3. Responses to direct questions about number of carcasses sold in the previous week that exceeded ten, so were capped for comparison with the modified bean method (see main text).

Year and survey group	number of responses	Responses with no answer recorded for direct question	Number of direct responses over 10	Median and range of values of responses over 10
group 1 2017	201	5	0	-
group 1 2019	181	0	1	13
group 2 2017	136	0	6	20.5 [12 – 40]
group 2 2019	168	0	0	-
non-project 2017	143	0	8	15 [11 – 36]
non-project 2019	175	0	3	18 [11 – 20]

Jones, S., Papworth, S., Keane, A., St John, F., Smith, E., Flomo, A., Nyamunue, Z., Vickery, J., 2019. Incentives and social relationships of hunters and traders in a Liberian bushmeat system. Biol. Conserv. 237, 338–347. https://doi.org/10.1016/j.biocon.2019.06.006

Appendix S4

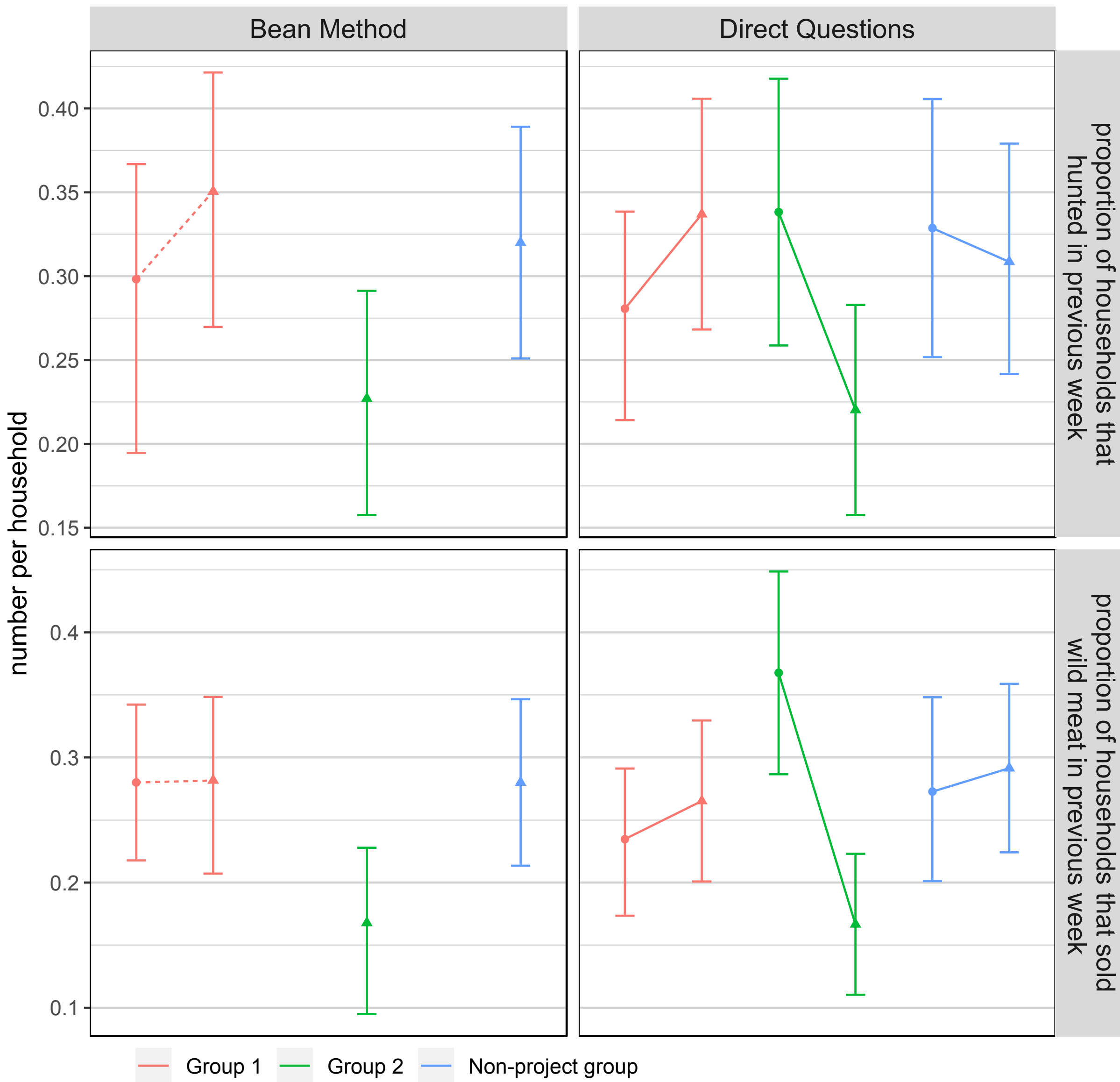

Figure S1. Proportion of households that had reported hunting or selling wildmeat during the previous week in 2017 (circles) and 2019 (triangles). Error bars show 95% confidence intervals. Values are not shown for Group 2 and Non-project Group in 2017, in which a version of the bean method was used which did not allow non-zero answers to be counted (see main text).

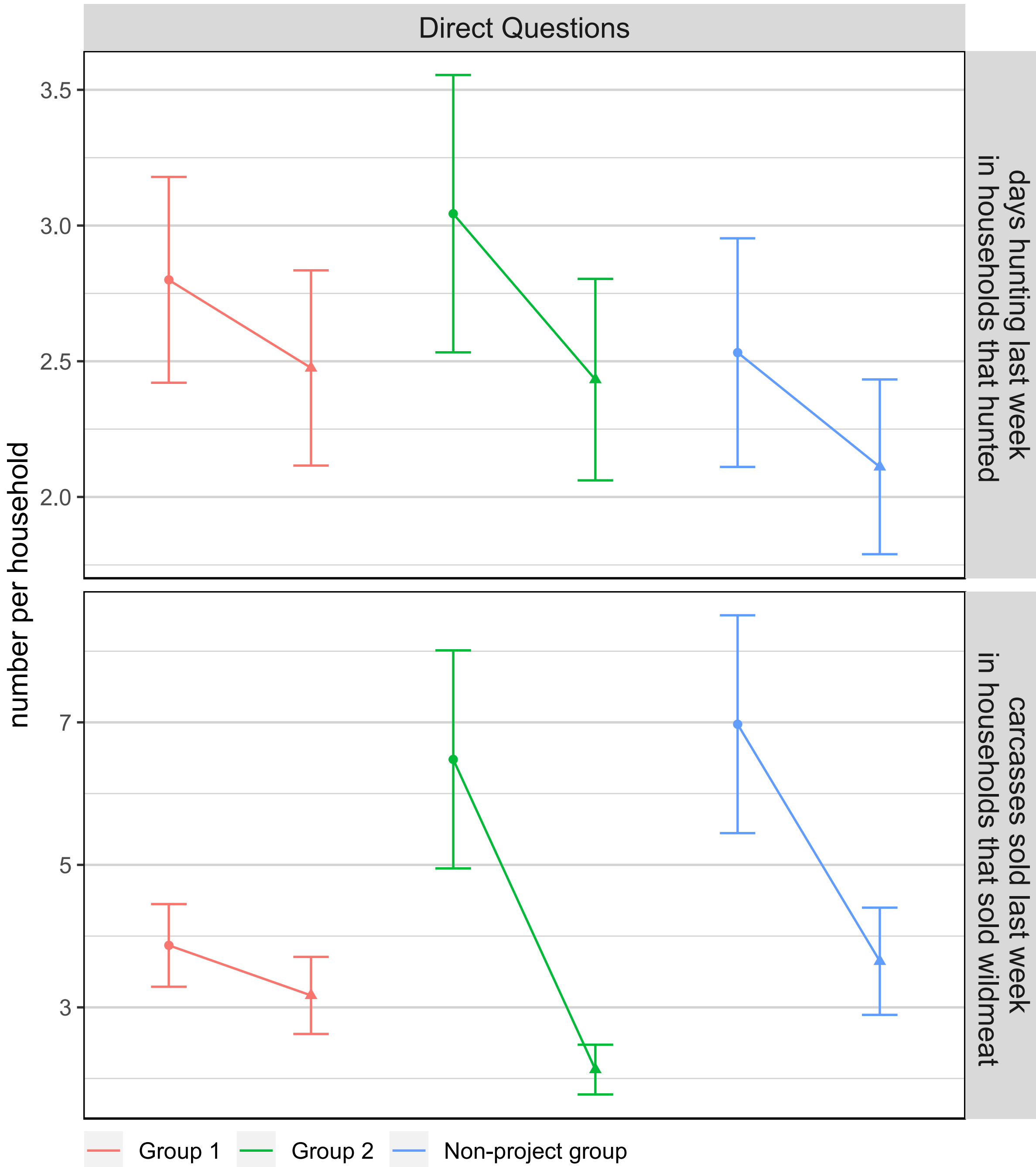

Figure S2. Mean number of days hunting and carcasses sold in the previous week among households that reported hunting or trading activity in the previous week in response to direct questions. Values shown are from direct questions and are not capped at ten carcasses per respondent. Error bars show 95% confidence intervals.

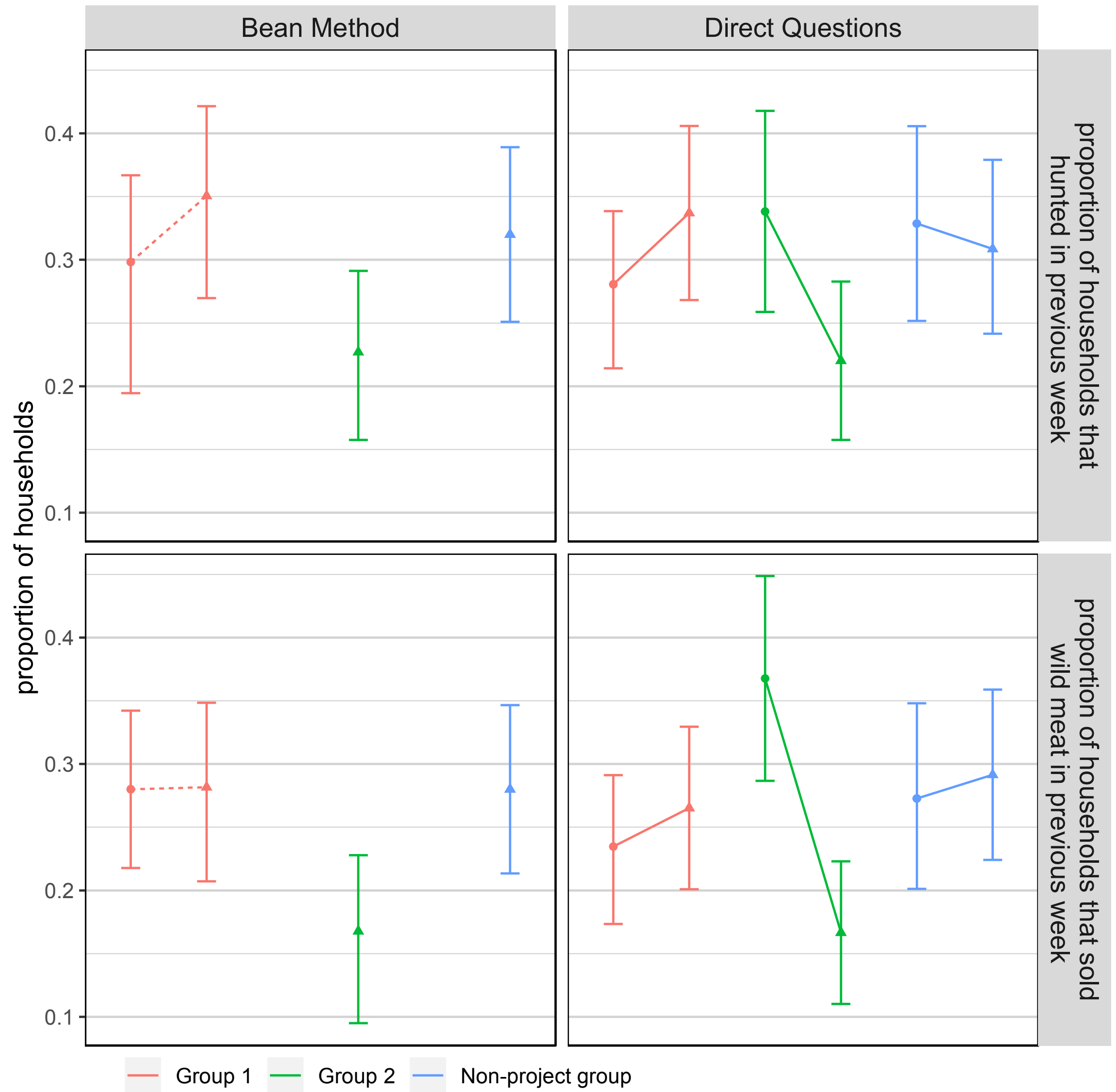

Figure S3. Mean number of days hunting and carcasses sold in the previous week among households that reported hunting or trading activity in the previous week. Direct question responses are capped at ten carcasses per respondent to match the data obtained using the modified bean method (see main text). Error bars show 95% confidence intervals.

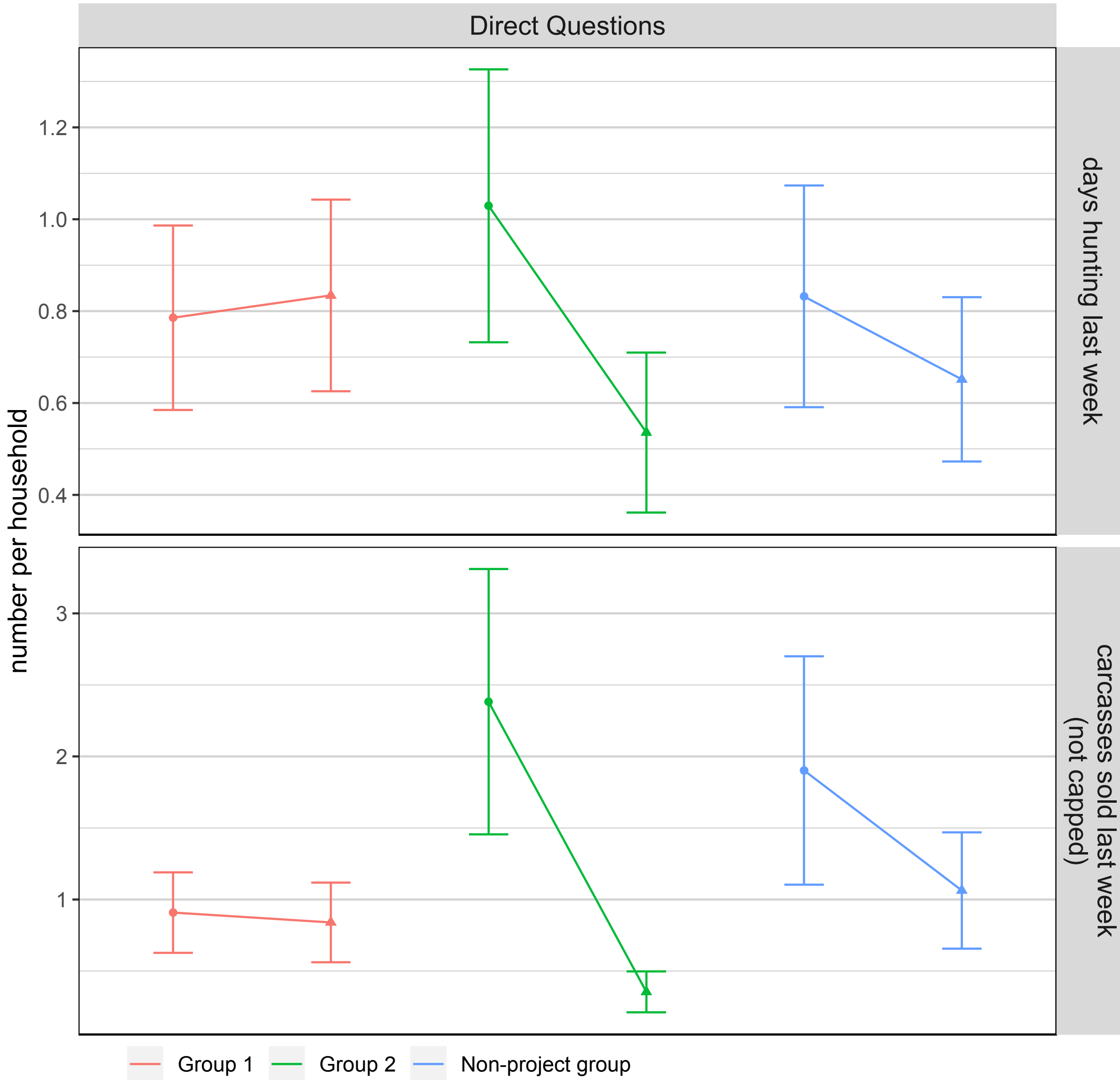

Figure S4. Mean number of days hunting and carcasses sold in the previous week, responses to direct questions not capped (see main text). Error bars show 95% confidence intervals.

Appendix S5

Separate administration of the bean method and direct questions

We examined whether responses to the bean method could have been influenced by the direct question section of the questionnaire, since respondents who had already answered a question directly may be likely to give the same answer using the bean method, whether or not it was truthful. To explore this, we split the questionnaire in one village so that respondents were only asked either the direct section or bean method sections (see main text), with interviewers alternating which section was administered between each household. This experimental manipulation was carried out in 2019 in project group 1, in a village that had not been previously surveyed in 2017. Respondents that were asked only with the direct method reported a similar level of hunting as those asked with only the bean method (28%, n=69 compared to 24%, n=67; chi-squared =0.08, df=1,p=0.77). Wildmeat trading prevalence was reported by 14% of direct respondents, and 25% of bean method respondents (chi-squared=1.89, df=1, p=0.17) and mining prevalence was 78% and 82% respectively (chi-squared = 0.12, df=1, p=0.73).

Appendix S6 Questionnaire

Name	
Head of household	
Age	male / female
Married / single	Married Single other:
Number of people in the household? over 16 years:_______ under 16 years:_______	
Highest education of adults in household?	
Is the head of household a born citizen?	Yes / no Tribe:
How many years has the head of the household lived in the community?	
Main activity that brings food into the household?	
Which of these activities has someone in this household done in the last 6 months?	
Garden: YES / NO Farming YES / NO Cocoa Plantation YES / NO Hunting YES / NO Dry meat business YES / NO Mining YES / NO Cook Shop YES / NO Selling meat: YES / NO	Charcoal: YES / NO Fishing: YES / NO Palm cutting: YES / NO Small business YES / NO Employment: YES / NO What type: Other:
Any other activities can bring money to your home?	
Is anyone in your house in the group for: Honey Bees: YES / NO Ground pea or Beans YES / NO Cocoa Farmer Field School YES / NO	Swamp farm YES / NO Small Loans group: YES / NO CFOC: YES / NO Other:

How many body of meat has anyone in your house sold in the past week? ___________
How many days this week has someone in your household been hunting? ____________

BEANS CUP 1:
For these questions, I don't want you to tell me the answer. You are going to make your answer like casting a vote, by putting beans into this jar without showing them to me. If the answer is NO then put a red bean into the jar.
1) In the past 6 months, has anyone in your house done dry meat business?
If the answer is YES, move a WHITE bean, if it is NO, move a red bean

2) In the past 6 months, has anyone in your house done hunting?
If the answer is YES, move a COUNTRY bean, if it is NO, move a red bean

3) In the past 6 months, has anyone in your house done mining?
If the answer is YES, move a COLOURED bean, if it is NO, move a red bean

BEANS CUP 2)
How many body of meat have you or anyone in your house sold in the past week? Put a RED bean in the cup if the answer is 0, or put the number of WHITE beans for the number of body.
No Answer (circle if no answer is given)
How many days this week has someone in your household been hunting? Put a BROWN bean in the cup if the answer is 0, or put the number of COUNTRY beans for the number of days.
No Answer (circle if no answer is given)

Appendix S7 Statistical comparison of start of project (n=480) and end of project (n=524), for the proportion of households that reported hunting or trading bushmeat in the previous six months, using two questioning methods (see main text).

	Direct method	Bean method
Hunting		
non-project group	X^2=1.66e-30, df=1, p=1	X^2=0.25, df=1, p=0.62
group 1	X^2=0.72, df=1, p=0.40	X^2=1.24, df=1, p=0.27
group 2	X^2=3.15, df=1, p=0.08	X^2=4.08, df=1, p=0.04
all groups	X^2=0.20, df=1, p=0.66	X^2=5.8 e-05, df=1, p=0.99
Trading		
non-project group	X^2=3.72, df=1, p=0.05	X^2=5.90, df=1, p=0.02
group 1	X^2=8.80, df=1, p=0.003	X^2=4.74, df=1, p=0.03
group 2	X^2=20.22, df=1, p<0.0001	X^2=29.00, df=1, p<0.0001
all groups	X^2=29.0, df=1, p<0.0001	X^2 = 32.1, df=1, p<0.0001
Mining		
non-project group	X^2=0.17, df=1, p=0.68	X^2=0.37, df=1, p=0.54
group 1	X^2=3.15, df=1, p=0.08	X^2=2.77, df=1, p=0.10
group 2	X^2=0.03, df=1, p=0.87	X^2=0.38, df=1, p=0.54
all groups	X^2=13.27, df=1, p=0.07	X^2=1.53, df=1, p=0.22

Chapter 6. Consequences of survey method for estimating hunters' harvest rates

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Consequences of survey method for estimating hunters' harvest rates

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Abstract

Harvest data are widely used to understand hunting in tropical forests. However, survey methods are susceptible to biases which could affect results. We compare catch data from two approaches applied concurrently in the same villages (n = 7) in Gola Forest, Liberia: hunter recall interviews (n = 208 hunters, 253 trips) and continuous monitoring by village-based assistants (n = 53 hunters, 404 trips). We use Bayesian multi-level models to: (a) compare estimates of animals killed per trip for each data source; (b) test whether differences between villages are consistent across data sources and (c) identify potential sources of bias. Hunter recall produced higher, and more variable, catch estimates than village-based monitoring, with mean of 7.3 animals [6.0–8.8 95%CI] compared to 3.0 [2.4–3.6], for a trip lasting 3.2 days (the average duration from village-based monitoring). Mean catch-per-village from village-based monitoring failed to predict hunter recall catch and villages with highest catch differed between methods. Differences in trip duration were a potential source of bias: hunter recall recorded longer, more variable, trips (mean 4.0 ± SD 3.0 days, range = 1–32) than village-based monitoring (mean 3.2 ± SD 1.7, range = 1–10). Longer trips were associated with higher catch-per-day, use of guns, forest camps and accompaniment by another person; so nonrandom sampling of these traits may have introduced bias. Between-hunter variability was lower with village-based monitoring, suggesting sampling captured a less diverse subgroup of hunters, or that recall data were noisier due to reporting errors. Our results demonstrate that methodological biases can have large effects on catch estimates and should be carefully considered when designing or interpreting hunting studies.

KEYWORDS

bushmeat, catch per unit effort, Gola Forest, hunting, measurement error, monitoring, social desirability bias, West Africa

1 | INTRODUCTION

Over-harvesting of tropical forest wildlife for consumption presents a major challenge for conservation (Benítez-López et al., 2017) and could impact livelihoods and food security of many people (Cawthorn & Hoffman, 2015). Datasets describing what hunters catch are useful for understanding this issue as they give insight into patterns of wildlife abundance (Weinbaum, Brashares, Golden, & Getz, 2013) as well as resource use (Grande-Vega, Carpinetti, Duarte, & Fa, 2013). Where hunting is openly practiced, catch data can be relatively easy to obtain, and there is a wealth of literature describing hunting statistics from across the tropics, dating back to the 1960s (Asibey, 1966; Taylor et al., 2015). However, catch and hunting effort can be measured in numerous ways, and methods are prone to measurement error or sampling bias from various sources (e.g., Jones, Andriamarovololona, Hockley, Gibbons, & Milner-Gulland, 2008; Rist, Rowcliffe, Cowlishaw, & Milner-Gulland, 2008). A clearer understanding of bias associated with catch data could help accurate interpretation of results and improve survey designs.

Catch data have been used in a range of studies, often with metrics of catch per unit effort or prey composition (e.g., Fa, Ryan, & Bell, 2005; Grande-Vega, Farfán, Ondo, & Fa, 2016; Ingram et al., 2015). Harvest information has been utilized to understand patterns of resource use (e.g., Duda, Gallois, & Reyes-Garcia, 2017; Gill, Fa, Rowcliffe, & Kümpel, 2012; Richard-Hansen et al., 2019; Wright & Priston, 2010) and ecological trends (e.g., Alvard, Robinson, Redford, & Kaplan, 1997; Brook et al., 2019; Constantino, 2016; Muchaal & Ngandjui, 1999), while monitoring of hunter returns is a valuable tool in community-based resource management (Marrocoli et al., 2019; Mortensen & Brit, 2012; Shaffer, Milstein, Yukuma, Marawanaru, & Suse, 2017; Yasuoka et al., 2015). In addition, studies that combine several data sources have been used to address questions at broad spatial or temporal scales (Ávila et al., 2019; Fa et al., 2005, 2016; Fa, Peres, & Meeuwig, 2002; Jerozolimski & Peres, 2003; Kamgaing, Dzefack, & Yasuoka, 2019; Peres, 2001). Information from at least 275 sites in West and Central Africa have been collated in an online database, OFFTAKE (Taylor et al., 2015) with ongoing efforts to develop indicators from harvest data for monitoring progress toward global conservation goals, and to guide regional policies (Ingram et al., 2015). Given this range of applications, it is important to understand the quality of catch data and extent to which results might be sensitive to limitations and biases of different survey methods (Noss, 1998; Rist et al., 2008).

Common approaches to collect catch data include hunter follows, in which researchers accompany hunters on trips (e.g., Colell, Maté, & Fa, 1994; Kümpel, Rowcliffe, Cowlishaw, & Milner-Gulland, 2009; Rist, Milner-Gulland, Cowlishaw, & Rowcliffe, 2010), interviews where hunters report previous activity (e.g., Duda et al., 2017; McEvoy et al., 2019), hunter diaries or log books (e.g., Noss, 1998; Stuart-Hill, Diggle, Munali, Tagg, & Ward, 2005), and village- or camp-based monitoring, where catch returned to a settlement or hunting base is recorded (e.g., Coad, 2007; Greengrass, 2016; Kümpel, Milner-Gulland, Rowcliffe, & Cowlishaw, 2008). Hunting effort is defined and measured in various ways, for instance, effort may be recorded in terms of hunting days, time spent actively hunting, number of snares deployed or distances travelled (e.g., Kümpel, Milner-Gulland, Cowlishaw, & Marcus Rowcliffe, 2010; Rist et al., 2008). Distance-based approaches include measures of distances walked by hunters, which might then be averaged for different areas in a landscape (Sirén, Hambäck, & Machoa, 2004), or proxies based on the observed pattern that hunting intensity typically decreases with distance from access points such as villages, roads or rivers (Parry, Barlow, & Peres, 2009; Sirén, Cardenas, Hambäck, & Parvinen, 2013). Spatially explicit approaches for quantifying harvest rates can help to identify potential impacts on wildlife populations (Levi et al., 2011; Levi, Shepard, Ohl-Schacherer, Peres, & Yu, 2009) and are relatively well-developed in fisheries management (e.g., Glaser, Ye, & Sugihara, 2014). In hunting studies, the incorporation of spatial aspects of hunter-prey dynamics has been facilitated by the use of GPS loggers (Brøseth & Pedersen, 2000) alongside advances in modeling and analytical techniques (Ling & Milner-Gulland, 2008; Papworth, Bunnefeld, Slocombe, & Milner-Gulland, 2012).

There are several mechanisms by which different methods to quantify harvest rates may incur bias. Variation in the way hunters are recruited, where data are recorded, and by whom, could influence data quality (Weinreb, 2006). Added to this, measurement error or nonrandom sampling might occur at the level of villages, hunters, hunting trips or prey species (Hill & Kintigh, 2009; Jones et al., 2008). Finally, the different measures of hunting effort used to interpret catch data introduce additional error (Rist et al., 2008). In general, the validity of catch per unit effort as an indicator of prey populations can be limited, since biologically-relevant hunting effort is hard to define (Rist, 2007), and relationships between catch, effort and prey abundance are rarely known (Maunder et al., 2006). Nonrandom sampling can introduce biases in hunting systems with high variability between hunters (e.g., Coad, 2007; Fa et al., 2016;

Kümpel et al., 2009). For example, hunters who rarely associate with settlements or camps are likely to be under-represented in many studies (e.g., McEvoy et al., 2019). Similarly, methods that rely on self-reporting may be susceptible to error if, say, social desirability bias leads to under- or over-reporting of effort, catch, or particular species, as respondents seek to present themselves more favorably (Tourangeau & Yan, 2007). Recall error can also affect data quality, and, as with social desirability bias, can vary due to details of survey design (Golden, Wrangham, & Brashares, 2013; Jenkins et al., 2011; Jones et al., 2008).

Previous comparisons of methods show that catch estimates can be sensitive to various aspects of survey design (Jones et al., 2008; Noss, 1998). This includes how effort is defined and measured (Rist et al., 2008) and how harvest is assessed, for example, as day-weighted or hunter-weighted return rates (Hill & Kintigh, 2009). Detection of trends may depend on whether sampling strategies maximize number of hunters or hunting trips (Rist et al., 2010). Harvest rates have been shown to differ substantially depending on whether estimates are extrapolated from hunter follows, self-reporting or consumption diaries (Golden et al., 2013; Noss, 1998). Management decisions based on harvest data could be affected by biases incurred during data collection. For instance, decisions about how to tailor conservation messages, or where to allocate resources, depend on accurately identifying the types of hunters or areas with the highest conservation impacts (Jones, Keane, St John, Vickery, & Papworth, 2019). Results derived from a skewed sample of hunters or villages may not give a robust picture of who or where to target. Nevertheless, minimizing potential bias through survey design is often difficult in practice, and its potential extent and implications for findings can rarely be quantified.

Thus, there are numerous avenues and mechanisms by which bias can be introduced to catch data. A better understanding of the likelihood, nature and extent of these biases will result in more accurate assessments of potential error and allow more realistic levels of uncertainty to be incorporated into management and policy recommendations, whilst at the same time helping to improve study design. This study addresses gaps in our understanding of the extent to which survey methods might produce different estimates of harvest rates. We explore the hypothesis that sampling biases and measurement errors differ according to data collection methods, producing results which are inconsistent between methods. To assess possible pathways for bias, we examine relationships between catch, hunting effort and behavioral characteristics of hunters which may be nonrandomly sampled. We explore how uneven sampling of longer or shorter hunting trips might introduce biases and consider two predicted pathways by which trip duration sampling could become skewed. The first predicts that continuous recording of hunting activity will sample a higher proportion of shorter hunting trips compared to "snapshot" surveys. The second predicts that post-trip resting periods are longer following longer or more successful hunting trips, such that surveys in which hunters are opportunistically encountered during resting periods in villages might sample a greater proportion of long, successful trips. We evaluate inconsistency between survey methods by quantifying the extent to which results from one method predict those of another and explore potential consequences for management decisions. Specifically, we consider whether results from two methods differ in terms of which villages appear to have the highest harvest rates, representing information which might be used to prioritize conservation efforts.

2 | METHODS

We examine bias in hunting surveys by contrasting two methods which illustrate common sampling strategies and constraints (Table 1). For each method, we drew on previous findings (e.g., Noss, 1998; Rist et al., 2008) and our own familiarity with the hunting system at our study site, to identify (a) possible sources of bias, and (b) survey design features likely to affect the nature and extent of these biases. For the first method, "village-based monitoring," a local assistant was recruited in each village to record information about catch of participating hunters each time they returned from a trip. Local assistants used datasheets and did not share identifying information about hunters with researchers. The second method, "hunter recall," was a questionnaire-based survey conducted by research technicians working for a conservation organization, in which hunters were asked to recall recent harvests. These methods use different sampling approaches: for village-based monitoring, data are a continuous record of hunting activity at specific locations (villages), over a period of time and many hunting trips are recorded from relatively few hunters. For hunter recall, data are a set of discrete hunting trips and many hunters are sampled, but number of trips per hunter is small. The two methods also illustrate survey designs that would be appropriate under different site-specific constraints, in terms of survey cost limitations, and the degree to which participants can be expected to openly share information (Gavin, Solomon, & Blank, 2010). Village-based

TABLE 1 Possible pathways for introduction of bias in the two survey methods for obtaining catch data, identified based on familiarity with the study site. Examples from the literature are given in which the studies' authors note that similar biases could have affected data quality

	Pathways for introduction of bias		
Sampling units	**Village-based monitoring**	**Hunter recall interviews**	**Potential consequences**
	A resident from each village recruits hunters and observes catch after each trip.	Questionnaires about most recent catch are administered to all known hunters by research technicians	
Villages	*Factors determining villages sampled* • Availability of a literate, willing local assistant • Sufficient hunters willing to participate (e.g., >5) • Accessibility to researchers • Good relationship between local citizens and researchers	*Factors determining villages sampled* • Accessibility to researchers • Good relationship between local citizens and researchers (Van Vliet & Nasi, 2008)	*Village-based monitoring*: • Over-represents large villages, with higher literacy *Both methods*: • Under-represent remote villages or camps. • Over-represent villages with long-term relationships with conservationists or researchers
Hunters	*Factors determining hunters sampled* • Willingness to participate • Hunters known to local assistant • Hunters based in villages	*Factors determining hunters sampled* • Willingness to participate • Hunters identified by research technicians (e.g., from household surveys) or by others (e.g., from snowball sampling)	*Village-based monitoring*: • Under-represents hunters who never or rarely return to villages (Bobo, Kamgaing, Kamdoum, & Dzefack, 2015) • Over-represents hunters in the local assistants' social network (e.g., long-term residents, indigenous citizens) *Hunter recall interviews*: • Under-represents hunters who do not self-identify as hunters, or who others do not know as hunters (Kümpel et al., 2010) *Both methods*: • Under-represent hunters engaged in illegal or illicit activity and unwilling to share information • Under-represent hunters who are not socially integrated (e.g., transient migrants, company employees)
Hunting trips	*Factors affecting hunting trip observations* • Hunter returns to village after trip • Local assistant meets with hunter after each trip • Short, frequent trips contribute more data points than long, infrequent trips	*Factors affecting hunting trip observations* • Short or unsuccessful trips may not be reported for example, a half-day excursion to check snares may not be considered as a "trip" (Grande-Vega et al., 2013) • Trips followed by long rest period in villages more likely to be sampled (hunters are encountered by researchers in villages)	*Village-based monitoring*: • Fewer long trips than short trips • Over-represents trips conducted close to villages (Bobo et al., 2015) *Hunter recall interviews*: • Over-represents trips followed by long rest periods (e.g., high catch, long travel distances) • Over-represents memorable hunting trips (e.g., high catch, rarely killed species)
Catch	*Factors affecting recorded catch* • Animals sold or eaten in the forest only recorded if reported by the hunter • Social desirability bias: Hunter may conceal catch from local	*Factors affecting recorded catch* • Large, unusual species more accurately recalled than small, frequently killed species (Golden et al., 2013; Parry et al., 2009)	*Village-based monitoring*: • Catch under-estimated if many animals are sold/consumed elsewhere (Kümpel et al., 2010) • Over-represents species brought to villages

TABLE 1 (Continued)

Sampling units	Pathways for introduction of bias: Village-based monitoring	Pathways for introduction of bias: Hunter recall interviews	Potential consequences
	assistants (e.g., due to local taboos, laws, or to keep income from high value species private) or exaggerate catch sold or eaten in the forest.	• Lower reporting accuracy of large carcass counts, for example, values given to the nearest factor or 5 or 10 (Vaske, Beaman, & Beaman, 2006), or shrunk to the mean (Jones et al., 2008) • Lower recall accuracy of events further in the past • Social desirability bias: hunters may under- or over-report particular species to give favorable impression, for example, to conceal species killed illegally or to appear more skilled (Duda et al., 2017; Kümpel et al., 2010; Wright & Priston, 2010)	*Hunter recall interviews*: • Lower accuracy associated with long trips, frequently killed species *Both methods* • Depending on direction of social desirability bias catch, or particular species, may be under- or over-estimated. Effects could vary across hunters and villages

monitoring represents a low-cost survey relative to hunter recall, as data collection can be carried out by (financially compensated) local members of the hunting community thus minimizing time and transportation costs relative to deploying full-time research technicians. Village-based monitoring is also more appropriate where hunting is somewhat sensitive, as unlike hunter recall, participants do not share information directly with external researchers. We examine consequences of these differences for estimating hunters' catch, defined as the number of animals killed by a hunter on a trip, including mammals and birds, and any animals sold or eaten in the forest (see Jones, Papworth, et al., 2019 for a list of species). We explore evidence for specific sources of bias by assessing covariates of hunting catch, trip duration and inter-trip resting period, to assess how nonrandom sampling of these variables or their correlates might skew results. We evaluate the degree to which results from the first method predict those of the second and explore implications of survey differences for informing management decisions. Specifically, we consider how results differ for understanding which villages have highest harvest rates and for predicting harvest rates of unobserved hunters or villages.

Work took place in the Gola Forest, Liberia, at the GolaMA conservation project site (details in Jones, Keane, et al., 2019; Jones, Papworth, et al., 2019). Hunter recall data were collected from all 18 villages within the study area, between July 2016 and July 2017. Village-based monitoring data were collected at seven of the villages in the study area, which were a nonrandom subset of villages where hunter recall surveys were administered, between September 2016 and March 2017. Analyses in which we compare results from both methods therefore utilize only the subset of hunter recall data collected from the seven villages in which village-based monitoring was applied. However, we do not exclude hunter recall observations ($n = 20$) made in April to August in which village-based monitoring data were not collected (see Figure S1). This was done in order to maximize sample sizes for estimating hunter- and village-level variability.

2.1 | Hunter recall interviews

A questionnaire was administered by trained research technicians via face-to-face interviews to all identified hunters from the 18 villages in the study area. Research technicians were GolaMA employees who visited villages for short periods (1–5 days), to conduct the survey. Hunters were identified through key informants, a previous household survey, and snowball sampling. If hunters were not initially available, researchers returned a minimum of three times before ruling out participation. Hunters were asked general questions about hunting practices and to provide details of their most recent hunting trip, including species killed and sale or consumption of carcasses. Hunters re-encountered on subsequent visits to villages were asked to repeat the questionnaire ($n = 48$), so each hunter provided details of up to three hunting trips. Time between repeat interviews ranged from 55 to 278 days (median = 149). Parts of this dataset, and information about hunters' livelihoods have been published in Jones, Keane, et al. (2019) and Jones, Papworth, et al. (2019).

2.2 | Village-based monitoring

Local assistants were recruited in a subset of seven villages in the study site. Assistants were village residents and self-declared hunters with basic literacy who were identified by research technicians after consultation with chief hunters. Villages were selected based on availability of a suitable local assistant. Assistants were responsible for recruiting hunters to participate in the study and recording catch over continuous monitoring periods of 1–3 months. Whenever a participating hunter returned to the village, local assistants recorded hunting trip duration in days and the number and species of animals killed, based on direct observation and the hunters' own reports of animals sold or eaten in the forest. Research technicians visited villages every 4–8 weeks to collect completed datasheets. Assistants coded hunters' identities on datasheets so that research technicians were unable to identify participating hunters. Participants were informed that their identity would not be revealed to research technicians or project staff.

2.3 | Ethics

Free, prior and informed consent was given verbally by all respondents who were informed that the study sought to understand hunting, answers would be confidential, and results would be published in reports and academic publications. Participants were informed that their names would not be linked to information they provided in any publication. Specific permission to conduct the study was obtained from local authorities and traditional leaders in each village, and village-based monitors were fairly compensated for their time. Ethical approval was obtained from Royal Holloway University of London ethics committee.

2.4 | Analytical framework

We used Bayesian multi-level models to estimate catch using a Poisson likelihood with log link function. Varying intercepts were included for hunters and villages. Weakly informative priors were specified as follows: general intercept = Normal (0,5), fixed variable coefficients = Normal (0,0.5), standard deviations of varying intercepts = Exponential (2). These reflected the prior belief that effect sizes were unlikely to exceed 1 in this setting. Continuous fixed variables were scaled by subtracting the sample mean and dividing by the sample standard deviation. All models were created with the Stan computational framework (http://mc-stan.org/) accessed using R (R Core Development Team, 2015) with package "brms" (Bürkner, 2017). Models were compared using pareto smoothed importance sampling or K-fold cross validation ($K = 10$ folds) if the pareto shape parameter exceeded 0.7 for many observations (Vehtari, Gelman, & Gabry, 2015), using package "loo" (Vehtari et al., 2019). Sampling was run for at least 4,000 post-warmup iterations, convergence was assessed based on Rhat values <1.01. Credible intervals were calculated as highest posterior density intervals.

2.5 | Predictors of catch

For hunter recall data, we modeled the number of animals killed on a trip (catch) as a response variable with predictors for trip duration (days), hunting method (snare, gun or both), season (early dry season, late dry season or rainy season), whether the hunter described themselves as being based in the town or at a forest camp and whether the hunter was accompanied by anyone else on the trip (e.g., another hunter or helper). The interaction between season and hunting method was included based on hunters' reports that dry leaf litter in late dry season made gun-hunting harder, whereas trappers were reportedly more successful as animals were predictably distributed near water sources. We compared models with all possible combinations of predictors, with trip duration and varying intercepts in all models (Table S4).

2.6 | Predictors of trip duration and post-trip rest period

For hunter recall data, trip duration (days) was modeled as a zero-truncated Poisson response with predictors for hunting method, season, hunting base and trip accompaniment. Models were compared for all combinations of predictors with varying intercepts for villages and hunters.

We tested whether post-trip resting period (days) was predicted by duration of previous trip, from hunter recall and village-based monitoring, since association between trip duration and resting period could be a cause of bias if sampling of trips is nonrandom with respect to resting period. For hunter recall, resting period was taken as number of days since a hunters' return from their previous trip plus the days they expected to rest until their next trip. For village-based monitoring, resting period was the days following a hunters' return from a trip until their departure on the next trip, as recorded by the local assistant (Supporting Information). For hunter recall we used zero-truncated Poisson likelihood, and for village-based monitoring, a zero-truncated Negative Binomial likelihood was used to improve fit. Previous trip duration (days) was included as a fixed effect, with varying intercepts for villages and hunters.

2.7 | Comparing catch estimates

We compared catch from village-based monitoring and hunter recall data collected from the same villages. We fit separate models to each dataset, using identical error structures and priors to make results as comparable as possible. Posterior parameter distributions were compared to assess differences in (a) estimated mean catch for a trip of given length; (b) estimated variation across hunters and villages; and (c) estimates of catch at the same specific villages.

To assess whether village-level patterns were consistent across data sources, we modeled average catch per day for villages, from village-based monitoring data, as a predictor of catch from hunter recall data. This village-catch variable was calculated from the raw village-based monitoring data as total catch divided by total trip-days, for each village. Village-catch was added as a predictor of hunter recall catch, in Poisson models with a covariate for trip duration and varying intercepts for villages and hunters. Additional predictors were added, in all combinations, for hunting method, season, hunting base and trip accompaniment. If village-based monitoring data predicted hunter recall observations perfectly, the slope and intercept parameters for the village-catch term would be 1 and 0, respectively. Deviation from these values was taken as an estimate of relative bias between data sources.

2.8 | Comparing predicted catch

Catch was simulated for a "new" hunter and village by drawing samples from the posterior distribution of each model, sampling parameter values of the hunter-level, village-level and population-level intercepts, then simulating catch from a Poisson distribution. The posterior distribution summarizes the probability that any given set of parameter values would produce the observed data, given the prior information and generative model. Sampling from the posterior generates parameter values at a frequency proportional to their expected probability, given the models' assumptions.

Values were simulated from 10,000 draws each from village-based monitoring and hunter recall models. Simulated values represented catch from a "new" hunter and village, for a trip of average duration and simulations were repeated for the village-based monitoring trip duration mean (3.2 days) and hunter recall mean (4.2 days).

3 | RESULTS

Village-based monitoring recorded shorter trips on average than hunter recall; the longest village-based monitoring trip was 10 days compared to 32 days in hunter recall (Table 2).

Mean prey size per trip was similar for both methods (Table 2). Excluding trips longer than 10 days ($n = 5$) from the hunter recall dataset did not alter these general patterns, giving mean trip duration of 3.7 days (*SD* 2.1, $n = 247$).

3.1 | Predictors of catch

The best supported model of hunter recall catch included hunting method, trip accompaniment, season and method-season interaction (Figure 1; Table S4). Trips in which hunters were accompanied (by another hunter or helper) had higher catch (estimate = 1.35, [1.16,1.57 95%CI]). Hunters using only snares or guns had lower catch than those using both methods (relative to using both, gun-use only = 0.81[0.64,1.04], snare-use only = 0.79[0.61,1.03]). There was some evidence that trips in the late dry season had lower catch than in early dry or rainy seasons and that snare-only hunters experienced relatively low catch in the rainy season, whereas this was not the case for hunters using guns (Figure 1).

3.2 | Predictors of trip duration and post-trip rest period

The best supported model of trip duration included hunting method, trip accompaniment and hunting base. A model with similar support also included season (Table S5). Longer trips were associated with use of guns or both guns and snares (estimate of snare-use relative to both =0.63[0.51,0.78]; Figure S3), with hunters being accompanied (estimate = 1.35[1.16,1.57]) and based in forest camps (estimate of town-based = 0.51[0.43,0.60]).

There was limited support from village-based monitoring data that post-trip resting period increased with previous trip duration (estimate = 1.07[0.99,1.17], probability that estimated effect is >0 = 0.95; Table S6, Figure S4), but not from hunter recall data (estimate = 1.06[0.92,1.16]; probability that estimated effect is >0 = 0.41).

TABLE 2 Sample sizes and attributes of catch data collected using two methods

	Hunter recall data, all villages	Hunter recall data, subset of villages with village-based monitoring	Village-based monitoring data
n villages	18	7	7
n hunters	208	106	50
n hunting trips	252	140	384
n hunting days	998	581	1,231
Mean trip duration in days *SD* (range)	4.0 *SD* 3.0 (1–32)	4.2 *SD* 3.3 (1–32)	3.2 *SD* 1.7 (1–10)
n carcasses	2,170	1,370	1,351
Mean catch per day	2.7 *SD* 2.4	3.0 *SD* 2.5	1.0 *SD* 0.8
Mean prey body mass per trip (kg)	14.9 *SD* 14.0	14.1 *SD* 8.6	14.2 *SD* 14.5

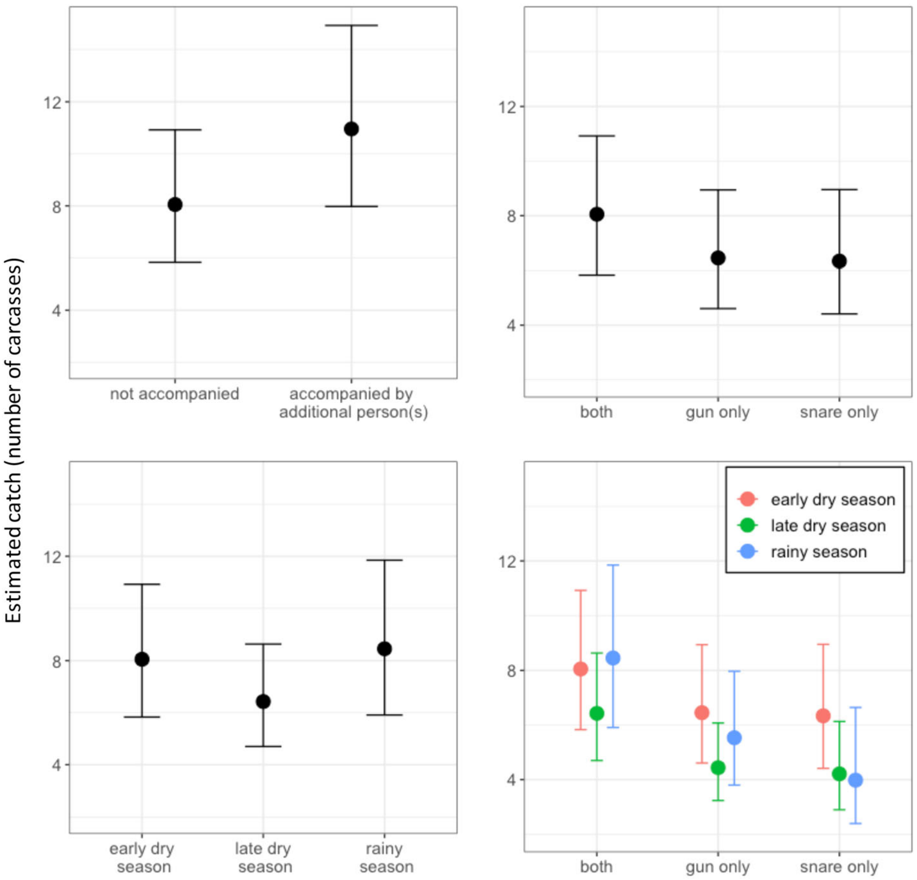

FIGURE 1 Conditional effects of hunting trip variables based on hunter recall data, showing posterior means (points) and 95% credible intervals (lines), based on a trip of 3.2 days, with covariates set at baseline levels (first level presented in plot)

3.3 | Comparing catch estimates from different survey methods

Estimated number of animals killed (catch) for a 3.2 day trip (the average duration observed with village-based monitoring), differed by approximately twofold between data sources (hunter recall estimate [95%CI] = 7.3 [6.0,8.8]; village-based monitoring = 3.0[2.4,3.6]; Table S7). Hunter recall produced higher and more variable, catch estimates than village-based monitoring (Figure 2). Estimated hunter-level variability was higher with hunter recall (*SD* estimate = 1.8[1.6,2.1]) than village-based monitoring (1.1[1.0,1.2]), whereas village-level variability was similar across data sources (Table S7). The above patterns held when three observations for trips over 10 days (i.e., the maximum observed in village-based monitoring data) were excluded from the hunter recall data (Supporting Information). Village-level variability of

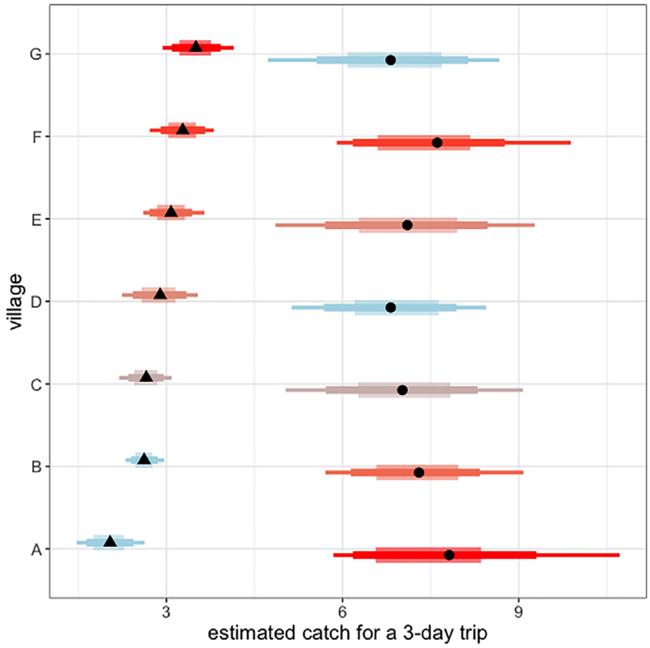

FIGURE 2 Predicted mean catch for an average hunter for each village, taken from models of village-based monitoring data (triangles) and hunter recall data (circles). Colors indicate ranks from highest mean catch (red) to lowest (blue), assigned to villages according to each data source. Points are mean predicted values, lines indicate 67%, 87%, and 97% CI

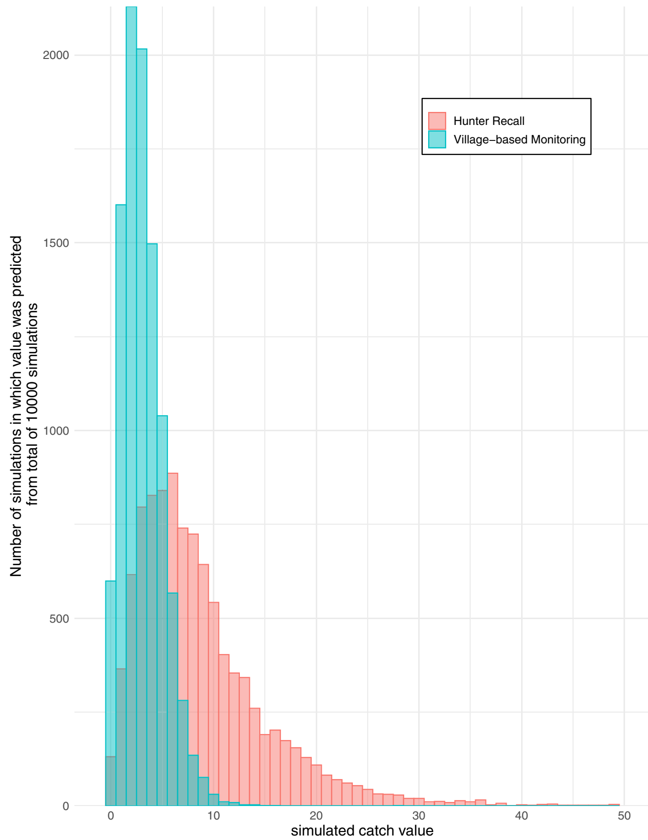

FIGURE 3 Distribution of simulated catch based on 10,000 draws from models of hunter recall and village-based monitoring data, collected at the same villages. Simulated values represent predicted catch of a "new" hunter and village for a 3.2 day trip (mean trip duration from village-based monitoring). For clarity, values above 50 are not shown (village-based monitoring: one value of 53, hunter recall: ten values from 50 to 65, one value of 120)

the full hunter recall dataset was higher (*SD* estimate = 1.7[1.4,2.3]) than the subset of data from villages with village-based monitoring (*SD* estimate = 1.1 [0.9,1.3]), suggesting the village-based monitoring subsample did not capture the overall variation across villages. The village with highest expected catch according to hunter recall had the lowest expected catch according to village-based monitoring (Figure 3). Hunter recall catch was not predicted by village average catch calculated from village-based monitoring (estimate = −0.29 [−0.89, 0.36]; Figures S6 and S7).

3.4 | Comparing predicted catch from different survey methods

New observations of animals killed on a hunting trip (catch), predicted from village-based monitoring had median of 3 animals [IQR 2–4] for a trip of 3.2 days (mean trip duration from village-based monitoring; Figure 3) and 4[2–5] for a trip of 4.2 days (mean trip duration from hunter recall). Predicted catch from hunter recall data was approximately twice as high, at 7[4–12] and 8[5–13] respectively for 3.2-day and 4.2-day trips. The village-based monitoring model predicted catch at least as large as the hunter recall median (8) in only 5% of simulated observations. The hunter recall model predicted catch equal or lower than the village-based monitoring median (3) in 11% of simulated observations.

4 | DISCUSSION

Differences between data collection methods could introduce biases that compromise the quality of catch datasets due to measurement error and nonrandom sampling. Our study is one of few to quantify the potential scale of these differences and highlights the extent to which outcomes can be sensitive to survey design. We found that estimated catch per day had a twofold difference depending on the source of data used, and that trip duration and hunter variability also differed.

The hunter recall method, where a large number of hunters provide information about relatively few trips, produced higher estimates of catch and hunter variability than village-based monitoring, where relatively few hunters contributed information about many trips. The magnitude of the differences suggests studies aiming to describe harvest patterns could reach different conclusions due to bias introduced during data collection: for example, apparent sustainability of hunting levels at a site may be affected by survey methods. The methods we compared could incur bias from several sources (Table 1), which are difficult to differentiate, and may vary substantially between sites or over time. Potentially important sources of bias can be considered in three categories: nonrandom sampling of hunters, reporting errors from self-reported information and representation of long versus short hunting trips.

First, we consider bias that may result from the way hunters are sampled. Lower variation in reported catch from village-based monitoring relative to hunter recall suggests the former sampled a more homogenous subset of hunters and villages. This may be because village-based monitoring, or indeed any method where a local assistant recruits participants, may favor sampling of indigenous residents, who are relatively settled or socially integrated and who may not represent the wider hunting community. Hunter information was not recorded with village-based monitoring, so hunter profiles cannot be directly compared between data sources. However, previous work at the site has shown that hunters can be grouped based on livelihood strategies, demography and hunting behavior (Jones, Keane, et al., 2019). Citizenship was an important feature defining group membership—with groups that had low harvest per day and low hunting effort being composed largely of indigenous citizens (Jones, Keane, et al., 2019). Thus, village-based monitoring may disproportionately sample from such groups and fail to capture the full spectrum of hunter types. This problem could be exacerbated if hunting by nonlocal immigrants is a contentious societal issue, as "outsiders" who are active, commercial, hunters may be reluctant to be scrutinized by a local data collector. Such social dynamics may be common to hunting systems elsewhere (e.g., Fa et al., 2016; Gill et al., 2012) and we suggest that attention to social context could improve study designs (Jones, Papworth, et al., 2019; Jost Robinson, Daspit, & Remis, 2011) and help ensure sampling adequately represents the range of hunters' sociodemographic and behavioral profiles.

Reporting error is a second likely source of bias in hunting studies that will vary with survey design (Jones et al., 2008). Whereas under village-based monitoring, catch and trip duration was observed directly by local assistants, hunter recall relied on information reported by hunters, making it potentially more susceptible to factors such as inaccurate recall (Golden et al., 2013), variation in how questions are interpreted (Schwarz & Oyserman, 2001), or deliberate misreporting (Tourangeau & Yan, 2007). These sources of error are challenging to address and could have added noise which increased the variability of hunter recall observations relative to village-based monitoring. Careful pilot testing can help minimizemisinterpretation of questions, but even this is hard to eliminate entirely. For instance, short, unsuccessful trips may be considered irrelevant by some hunters when asked about their "most recent hunting trip." Trips involving multiple hunters may produce ambiguity in which catch to report, for instance if snares set by one hunter were later checked by someone else. The pattern that accompaniment was associated with higher reported catch could have arisen if hunters reported combined catch, for example. In our study, it is possible that hunters were accompanied by other hunters who were themselves study participants. While in our case, the timing and durations of reported trips gave no indication that identical hunting trips were reported by different hunters, the issue is worth highlighting as double-reporting might exacerbate sampling biases or compromise the validity of statistical analyses. Our findings raise the question of whether data sources relying on reported information have consistently higher variability than those based on direct observations. Such a pattern could have consequences for design of monitoring programs, as methods that generate noisier data can be less efficient for detecting trends (Rist et al., 2010).

A third source of bias relates to the relative contribution of short and long hunting trips to datasets. Trip duration is associated with other measures of effort, such as distance travelled or number of snares deployed (Kümpel et al., 2009; Parry et al., 2009; Rist et al., 2008), and different data collection methods may inherently generate samples that weight trips differently. For instance, methods in which each hunter reports only their most recent trip, such as hunter recall, will likely record a lower proportion of shorter trips than continuous monitoring approaches, in which multiple short trips by the same hunter are all recorded. Extremely long trips, from which hunters return less frequently, will be relatively rare in continuous monitoring data but may be more readily captured by a "snapshot" sampling approach like that of the hunter recall method. In addition, if long trips are followed by longer rest periods in villages, any given hunter may more likely be encountered in a village following a long trip than a short one. We found limited support for these predictions; trips recorded by village-based monitoring were shorter and less variable on average, with 90% of observations for trips of up to 5 days, compared to 78% in hunter recall. Trips over 10 days were not observed with village-based monitoring yet represented 2% of hunter recall observations. However, only village-based monitoring data suggested there was a positive relationship between resting time and previous trip duration. If such patterns are consistent, there may be a predictable skew in trip lengths linked to snapshot sampling methods versus continuous recording approaches.

Where long and short trips are nonrandomly sampled, variables that correlate with trip duration will also be skewed, potentially adding to bias. We found that factors associated with higher catch (trip accompaniment, and use of both guns and snares) were also associated with longer trips. While effect sizes were relatively small and there is considerable overlap in predicted catch for trips with different attributes (Figure 1), the observed patterns had reasonable statistical support (Supporting Information) and are reflected in similar findings elsewhere (Coad, 2007; Kümpel, 2006). Trip accompaniment and hunting method variables can be considered as components of overall hunting effort: a parameter that is notoriously challenging to quantify (Rist et al., 2008) but which is important to minimize potential bias from uneven sampling of trip lengths. In our study, a more comprehensive definition of effort, for instance, accounting for number of snares or time spent actively hunting, might have improved agreement between the two methods. More generally, a clear understanding of the relationships between trip duration, effort and catch at any given site could help clarify how representative a sampling approach is likely to be.

The nature and extent of bias incurred by different survey methods may have implications for management decisions. Defining a “high” or “low” hunting offtake is important to differentiate hunter types and identify potential target groups (Dobson, Milner-Gulland, Ingram, & Keane, 2019), which could lead to the development of more effective behavior change interventions (Jones, Keane, et al., 2019). In our study, a new observation of 2.2 prey items per day would be considered high under village-based monitoring but typical according to hunter recall data. If resources are allocated according to level of harvest across villages, the fact that different methods might give different answers is problematic. Furthermore, biases are compounded wherever results are extrapolated to larger scales. For instance, extrapolations based on 100 hunting days/year would give 140–250 animals/hunter from hunter recall, compared with 75–120 from village-based monitoring. Study design is inevitably a trade-off between data quality and survey costs. For example, village-based monitoring was relatively low-cost but provided little detail about hunting trips and sampling of hunters was nonrandom. Such severe sampling constraints may be uncommon, but most hunting studies face data quality constraints to a lesser or greater degree. The discrepancy between survey methods found in this study and others (e.g., Golden et al., 2013; Noss, 1998) suggests hunting statistics should be interpreted cautiously.

Our findings demonstrate that those planning or interpreting hunting surveys should carefully consider where bias could occur. In particular, how well a given sampling approach is likely to represent the full range of hunters' behavioral profiles, the weighting given to trips of different lengths and what types of reporting error may occur. The specific aims and budget of a survey will dictate which methods are most appropriate for any given situation. However, some problems identified in our study could be minimized by application of rigorous sampling strategies and carefully designed survey instruments. For instance, randomized or stratified sampling techniques could help give a more balanced representation of different types of hunters or hunting trip durations, although such sampling strategies typically depend on being able to identify hunters in the first instance which is often not viable where hunting is prohibited. Additionally, development of survey instruments that address reporting errors (Schwarz & Oyserman, 2001) or social desirability bias (Nuno & St. John, 2015) could reduce these issues. Application of more than one survey method can also help to counter issues of data quality by offering a means to compare results and triangulate findings from different data sources (Keane, Jones, & Milner-Gulland, 2011).

Harvest datasets are a valuable, versatile resource for understanding hunting systems. However, studies likely encompass a range of data quality and results can be skewed by nonrandom sampling or measurement error from multiple sources. Added to this, patterns of bias are unlikely to remain consistent through time due to shifts in hunting practices and socio-political landscapes (Coad et al., 2013; Duda et al., 2017; Gill et al., 2012). Of the potential sources of bias identified for our study, only one, preferential recall of larger species, seemed unlikely from the data. Future work to disentangle the impacts of different mechanisms could provide valuable insight that might help ensure appropriate levels of uncertainty are incorporated into management decisions. Through a better understanding of the accuracy of harvest data, conservationists will be better placed to address the problem of over-hunting as a global driver of biodiversity loss.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interests.

AUTHOR CONTRIBUTIONS

All authors contributed to study conception and design, interpretation of results, and redrafting of the article. Sorrel C. Z. Jones conducted data collection and wrote the original article. Statistical analyses were performed by Sorrel C. Z. Jones, with further contributions from Aidan M. Keane and Sarah K. Papworth.

DATA AVAILABILITY STATEMENT

The data used in this study will be made freely available upon request, along with R code used to perform analyses. Village names or locations will not be provided for protection of study participants.

ETHICS STATEMENT

Ethical approval for this study was given by Royal Holloway University of London ethics committee (application ID 289). Free, prior and informed consent was obtained for all participants, and participants were informed their identities would be confidential.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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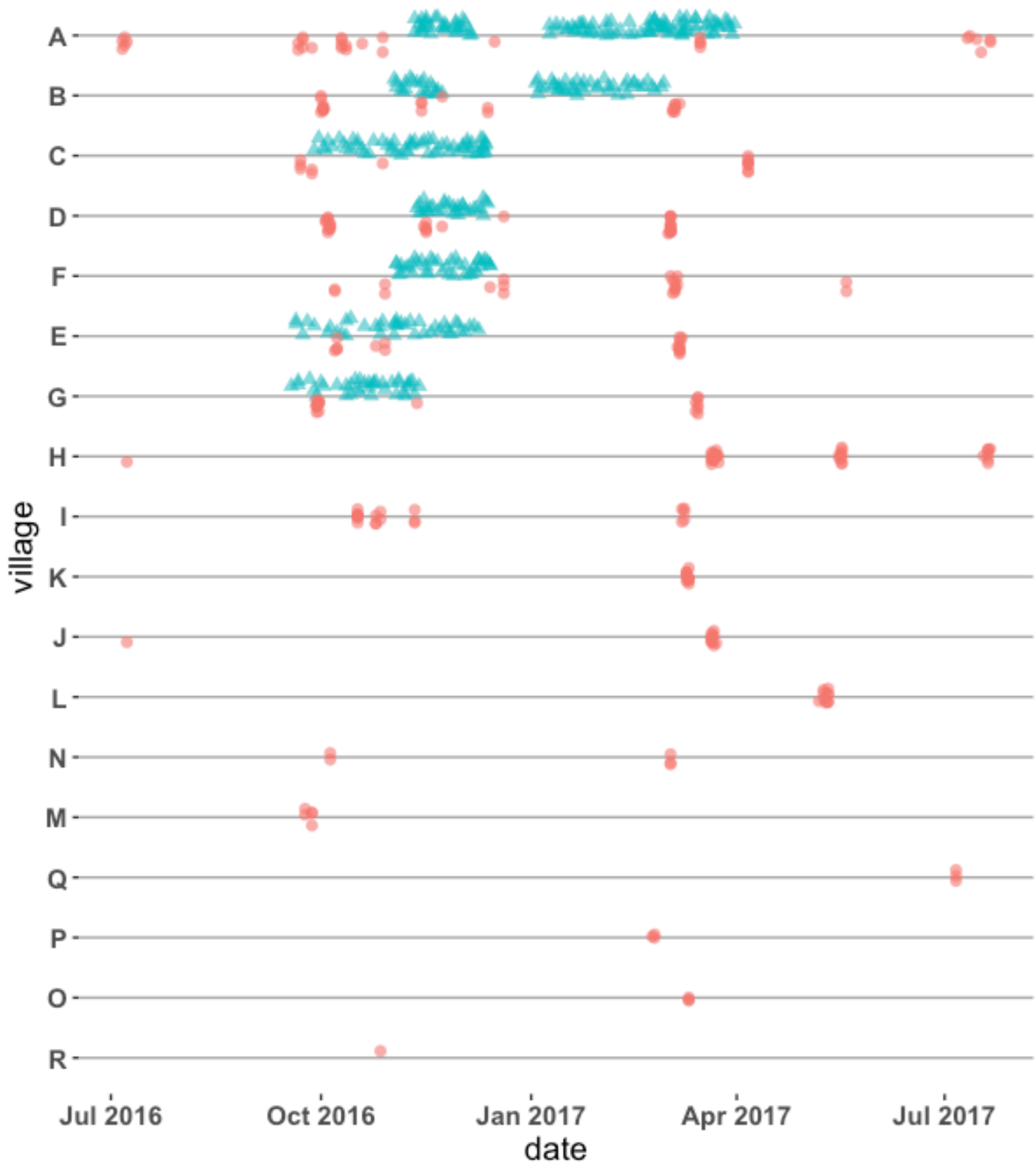

Fig S1. Temporal sampling of catch data using hunter recall (circles, red) and village-based monitoring (triangles, blue) in all villages in the study. Each point represents a hunting trip observation. Villages are ordered by total sample size of hunting trips (smallest to largest). Vertical displacement has been added to reduce overplotting.

Relationships between hunting trip variables

We explored relationships between predictors of catch that were recorded using hunter recall interviews: hunting method (snare, gun or both), trip accompaniment (hunter was accompanied by another person, or unaccompanied), hunting base (hunting is conducted from the village, or hunter uses a forest camp) and season (early dry, late dry, rainy). Chi-squared tests were used to evaluate associations between predictor variables.

Hunting method was non-randomly distributed with respect to trip accompaniment (χ^2 (2, N=252) = 20.27, p<0.0001) and hunting base (χ^2 (2, N=252) = 16.37, p = 0.003; Table S1). Trips in which hunters used both methods had a higher frequency of accompaniment than expected and were more frequently hunters that habitually based in forest camps. By contrast, use of either guns or snares was associated with a higher proportion of unaccompanied trips, and gun and snare hunters more frequently based in villages (Table S1).

Being based in forest camps was associated with accompaniment on trips (χ^2 (1, N=252) = 20.62, p<0.0001); in 92% of accompanied trips, hunters were habitually based at a forest camp (Table S2). Season was randomly distributed with respect to method (Table S3; χ^2 (4, N=252) = 4.16, p=0.38), accompaniment (χ^2 (2, N=252) = 2.23, p = 0.33) and base (χ^2 (2, N=252) = 0.80, p=0.67).

Table S1 Distribution of trip-level covariates with respect to hunting method in hunter recall data (n=252 hunting trip observations)

	Trip accompaniment[a]		**Hunting base[b]**		**% trips**
Hunting Method	*accompanied*	*unaccompanied*	*Forest camp*	*Village*	
Both Guns and Snares	*50*	*47*	*74*	*23*	*38%*
Gun only	*23*	*76*	*57*	*42*	*39%*
Snare only	*14*	*42*	*25*	*31*	*22%*
% trips	*65%*	*35%*	*62%*	*38%*	

[a] Chi-square test: χ^2 (2, N=252) = 20.27, p<0.0001
[b]Chi-square test: χ^2 (2, N=252) = 16.37, p = 0.003

Table S2 Distribution of trip-level covariates with respect to hunting method in hunter recall data (n=252 hunting trip observations)

	Trip accompaniment[a]		**% trips**
Hunting base	*Accompanied*	*unaccompanied*	
Forest camp	*71*	*85*	*62%*
Village	*16*	*80*	*38%*
% trips	*65%*	*35%*	

[a] Chi-square test: χ^2 (1, N=252) = 20.62, p<0.0001

Table S3 Distribution of observations according to hunting method and season, in hunter recall data (n=252 hunting trip observations). Chi-square tests show distribution was not significantly uneven.

	Season			**% trips**
Hunting Method	*early dry*	*late dry*	*rainy*	
Both Guns and Snares	28	49	20	38%
Gun only	26	52	21	39%
Snare only	23	25	8	22%
% trips	31%	50%	19%	

Effects of hunting trip variables

Catch recorded by hunter recall was modelled as a Poisson response, with predictors for hunting method, season, trip accompaniment and hunters' base (see main text for details). Several models were explored and compared with K-fold cross-validation using K=10 folds (Table S4). Pareto smoothed importance sampling approximation showed a high number of observations had pareto k parameter > 0.7 so this approach was not used for model comparison (Vehtari, Gelman and Gabry, 2017). Weakly informative priors were specified: intercept = Normal (0,5); predictor coefficients = Normal (0,0.5); standard deviation of varying intercepts = Exponential (2).

The best supported model included hunting method, season, method-season interaction and trip accompaniment. Posterior estimates are shown in Figure S2. The posterior parameter distribution for trip accompaniment suggests reasonably strong support for a positive effect of accompaniment, with none of the probability mass for the parameter estimate close to 0 (Fig S2). The difference in expected catch for accompanied versus unaccompanied trips had a median of 2.9 [1.4 – 4.6] 95% highest density interval (HDI), again showing no overlap with zero, which is suggestive that there is a difference in catch associated with accompaniment. For hunting method there was some support that use of guns and snares was associated with higher catch, with posterior parameter distributions of gun-only or snare-only methods having most of the probability mass below 0 (Fig S2). The difference in expected catch for gun-only hunters versus hunters using both guns and snares, had median -1.6 [-3.5 – 0.2] 95%HDI, for snare-only hunters it was -1.7 [-3.6 – 0.3]. The small degree of overlap with zero in these intervals indicates that, while it is most likely there is a small difference in catch associated with hunting methods, the support for this pattern is not overwhelming. It should also be noted that at the scale of predicted outcomes, there is a large overlap in the range of predicted values associated with these factors (see main text, Figure 2).

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Addition of hunting base resulted in a model with only slightly lower support (difference in expected log predictive density = -8 SE 5.61; Table S4). This alternative model provided little support that hunting base predicted catch, after accounting for the effects of hunting method, accompaniment and season (estimated effect of town-based=-0.11[-0.28,0.07 95%CI], probability effect of town-based<0=0.89). However, the explanatory factors hunting method and accompaniment were each somewhat correlated with hunting base (Table S1). The model which only included trip duration and hunting base suggested some support that being based in forest camps was associated with higher catch, when method or accompaniment were not accounted for (estimate of town-based = -0.15[-0.33,0.03], probability effect of town-base is<0 = 0.95).

Table S4. Comparison of models of catch from hunter recall data, based on K-fold cross validation (K=10 folds). Parameters were estimated for categorical variables: HM=hunting method (snare, gun or both), TA=trip accompaniment (hunter was unaccompanied, hunter was accompanied by at least one other person), S=season (early dry, late dry, rainy), HB = hunter's habitual base (village, forest camp), days=trip duration in days. Interaction is denoted by variable1:variable2. Unless otherwise stated, all models included varying intercepts at the hunter- and village- levels.

Model parameters	difference in expected log predictive density	S.E. difference in expected log predictive density
days+HM+S+TA+HM:S	0	0
days+HB+HM+S+TA+HM:S	-8	5.61
days+HM+S+TA	-10.37	7.89
days+HB+HM+S+TA	-10.95	8.09
days+HB	-14.56	16.15
days+HB+HM+S	-21.19	9.66
days+HM+TA	-22.11	8.58
days+HM	-23.45	21.26
days+HM+S	-24.58	11.97
days+TA	-25.52	10.58
days+S+TA	-27.35	18.81
days+HB+HM+S+HM:S	-29.68	9.57
days+TA+HM	-33.01	13.99
days+HB+TA	-33.4	14.31
days+HM+TA+HM:TA	-35.57	13.56
days+S	-48.8	19.38
HM	-64.74	25.7
days	-69.08	32.29
days+HB+S	-75.7	45.01
intercept only (varying hunter and village-level intercepts)	-93.04	33.82
intercept only (varying village level intercept only)	-221.2	54.13
days (varying hunter-level intercept, covarying slope and intercept at village-level)	-328.21	272.73

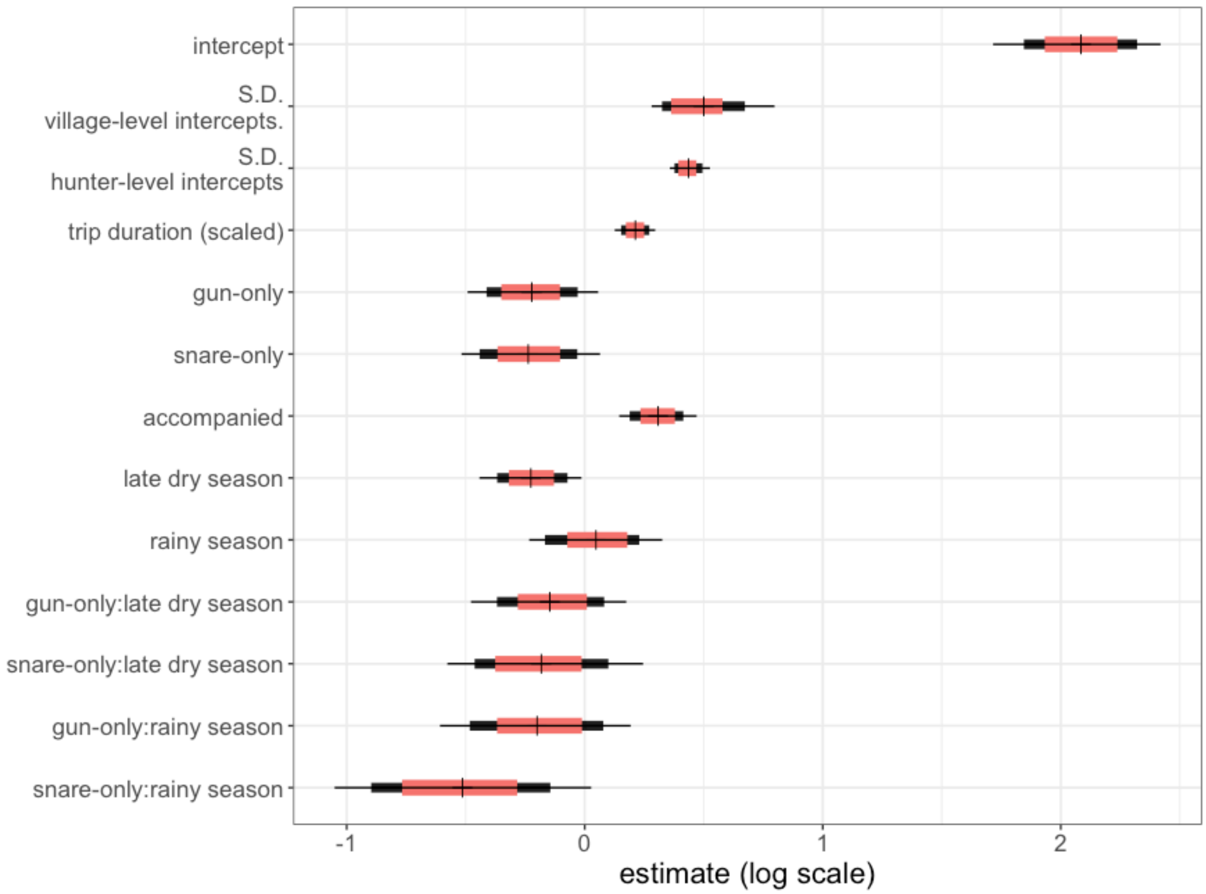


Fig S2. Posterior parameter estimates of the best supported model of hunter catch (animals killed per trip), recorded from hunter recall interviews (n=252). Catch was modelled as a response variable in Poisson multi-level models, with varying intercepts for villages and hunters. Mean posteriors with 67%, 87% and 97% CI (highest posterior density interval) are shown for the effects of hunting method (gun-only and snare-only, relative to using both guns and snares), trip accompaniment (hunter was accompanied by someone on trip, relative to being unaccompanied), season (late dry season and rainy season, relative to early dry season) and trip duration in days, scaled by subtracting the mean and dividing by standard deviation.

Variables related to trip duration

We explored factors related to trip duration in hunter recall data, using multilevel models with zero-truncated Poisson likelihoods and log link function. Trip duration in days was fit as the response variable, with predictors for hunting method, trip accompaniment, hunting base and season, and varying intercepts for villages and hunters. Models were compared with pareto smoothed importance sampling, implemented with package 'loo' (Vehtari et al., 2015). The best supported model included method, accompaniment and hunting base, but received similar support as a model which also included season (Table S5). Longer trips were associated with use of both guns and snares, trips in which hunters were accompanied (by another hunter or helper), and hunters who used forest camps (Fig S3). There was weak evidence that trip duration varied according to season (estimated effect in the full model, relative to early dry season: late-dry =-0.12[-0.30,0.07 95%CI]; rainy=0.15[-0.06,0.36]).

Table S5. Comparison of alternative models of trip duration (in days) from hunter recall data, based on pareto smoothed importance sampling. Categorical variables: HM=hunting method (snare, gun or both), TA=trip accompaniment (hunter was unaccompanied, hunter was accompanied by at least one other person), S=season (early dry, late dry, rainy), HB = hunter's habitual base (village, forest camp). Unless otherwise stated, model structure included varying intercepts at the hunter- and village- levels.

Linear covariates	difference in expected log predictive density	S.E. difference in expected log predictive density
HM+TA+HB	-	-
HM+TA+HB+S	-1.0	3.0
TA+HB+S	-6.1	5.2
TA+HB	-6.5	4.2
HM+HB	-6.7	3.9
HM+HB+S	-7.6	5.9
HB+S	-12.6	6.7
HB	-15.6	5.4
HM+TA	-18.4	8.3
HM+TA+S	-18.7	9.2
TA	-28.3	9.9
HM	-28.4	9.2
TA+S	-29.1	11.5
HM+S	-31.0	9.2
S	-44.7	11.3
village-level varying intercept only	-75.0	22.9
intercept only	-89.9	29.1

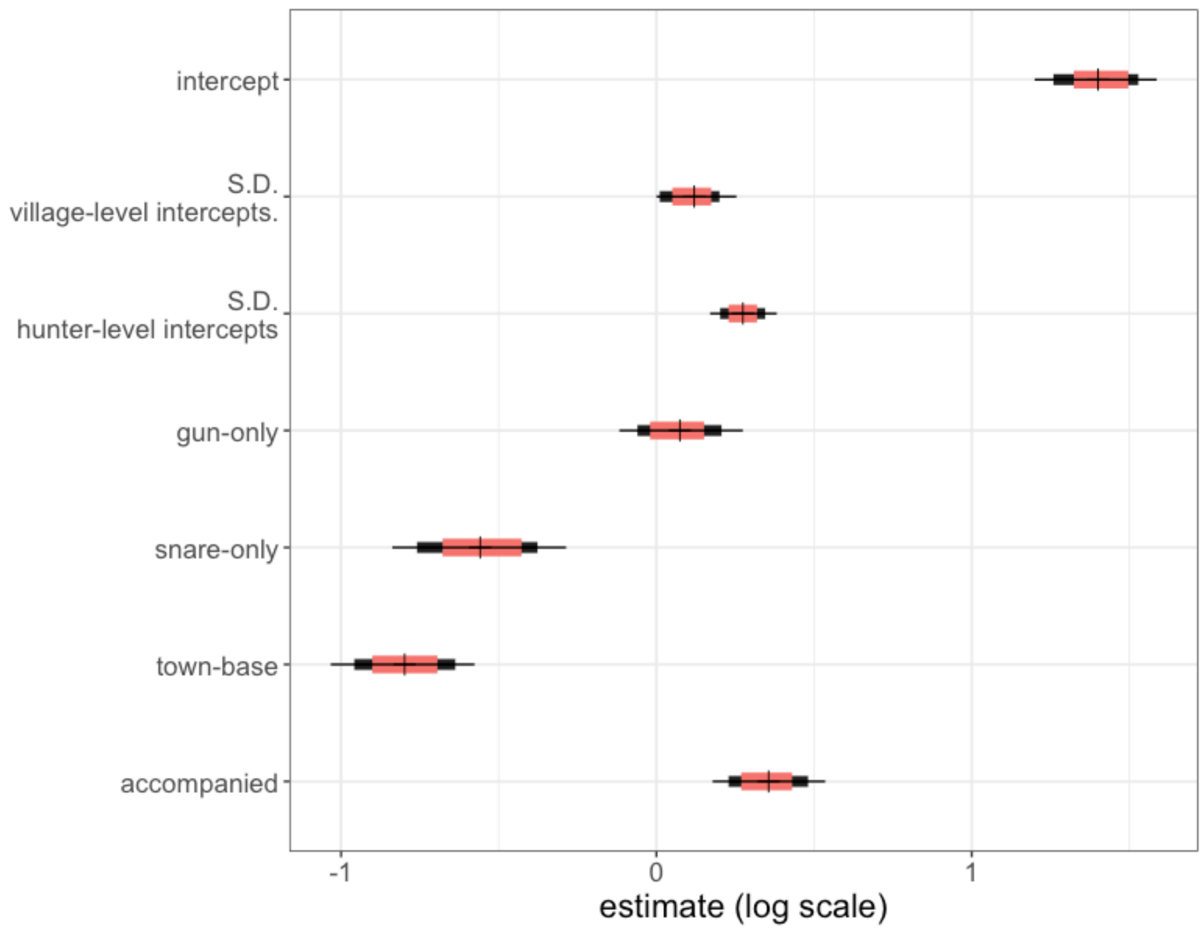


Figure S3 Posterior parameter estimates of the best supported model of hunting trip duration, recorded from hunter recall interviews (n=252). Trip duration was modelled as a response variable in zero-truncated Poisson multi-level models, with varying intercepts for villages and hunters. Mean posteriors with 67%, 87% and 97% CI (highest posterior density interval) are shown for the effects of hunting method (gun-only and snare-only, relative to using both guns and snares), trip accompaniment (hunter was accompanied by someone on trip, relative to being unaccompanied) and hunters' habitual base (town-base relative to basing in a forest camp).

Variable related to post-trip resting period

There were 136 trip observations for which post-trip resting period values were available in hunter recall data, and 314 observations in village-based monitoring data. Values from village-based monitoring where dates appeared to have been mis-recorded by the monitor were identified, in which the hunter was recorded returning from one trip after departing for the next trip. In six cases where the discrepancy was within two days, we assumed the rest period was the minimum of one day. One case with a larger error of four days was omitted.

Resting period was fit as a zero-truncated Poisson response in the hunter recall data, and zero-truncated Negative Binomial model in village-based monitoring data, as this gave a better fit (difference in expected log predictive density = -125.8 S.E 27.1). We specified the following weakly informative priors, for models of both datasets: intercept = Normal (0,5); predictor coefficients = Normal (0,0.5); standard deviation of varying intercepts = Exponential (2).

There was weak support for a small positive relationship between post-trip resting period and duration of previous trip from village-based monitoring data (Fig S4, Table S6; evidence ratio for effect >0 =20.28, probability=0.95). For hunter recall data, there was no evidence for a relationship (Table S6; evidence ratio for effect >0 =0.69, probability=0.41).

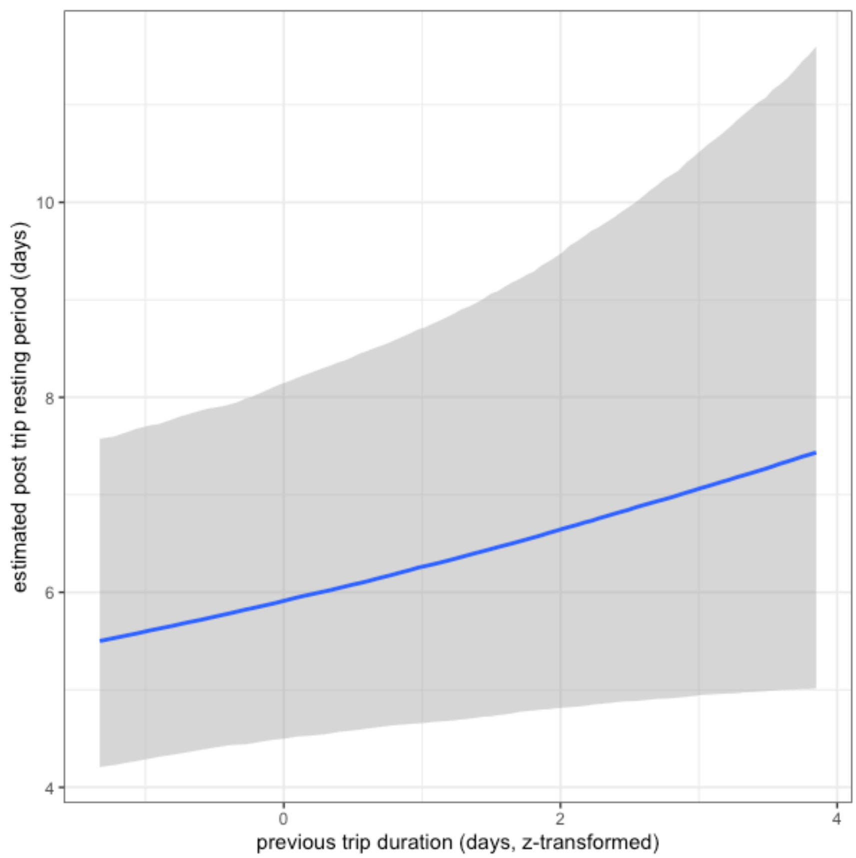


Fig S4 Conditional effect (posterior mean and 95% CI) of previous trip duration on post-trip resting period from village-based monitoring data (n=314 trips). Results are from a zero-truncated Negative Binomial multi-level model with varying village- and hunter-level intercepts. Trip duration was centred on the mean (3.31) and scaled by the standard deviation (1.74).

Table S6 Summary of models to estimate post-trip resting period (days) as a linear function of previous hunting trip duration (days) with random intercepts for villages and hunters, based on models with zero-truncated Poisson likelihood (hunter recall data) or zero-truncated Negative Binomial likelihood (Village-based monitoring).

Parameter	Village-based Monitoring n=314 trips, 7 villages		Hunter Recall n= 136 trips, 16 villages	
	Estimate [95% CI]	Estimate error	Estimate [95% CI]	Estimate error
Standard deviation of hunters	0.05 [0.00,0.14]	0.04	0.47 [0.39,0.57]	0.05
Standard deviation of villages	0.46 [0.25, 0.84]	0.16	0.27 [0.11, 0.47]	0.09
Intercept	1.65 [1.26,2.03]	0.19	1.98 [1.79,2.16]	0.09
Trip duration (scaled)	0.07 [-0.01, 0.16]	0.04	-0.01 [-0.10, 0.08]	0.04
Estimated shape parameter	3.23 [2.37,4.30]	0.50	-	-

Comparison of catch estimates from different survey methods

Estimates of catch from models fit to hunter recall and village-based monitoring are shown in Table S7. The same model structure was used across all data sources, using Poisson likelihood and log link function. Number of animals caught per trip was modelled as the response variable with a linear term for trip duration in days and varying intercepts at the level of villages and hunters. The posterior distribution of parameters is presented in Fig S5.

A small proportion (2%, n=3) of hunting trips recorded by hunter recall in villages with village-based monitoring, were longer than 10 days which was the maximum duration of village-based monitoring observations. Refitting the model without these observations, for the subset of villages with village-based monitoring, did not substantially change estimated values or overall patterns (posterior mean and 95% highest posterior density intervals, Intercept [i.e. mean catch on a 3.2-day trip] = 7.2 [5.9,8.6], hunter-level variance = 1.6 [1.5,1.8], village-level variance = 1.2 [1.0,1.4], n=137 hunting trips; values that are similar to results from models that included all trips shown in Table S7).

Table S7. Estimated hunters' catch based on two data sources. Values are mean and 95%CI (highest probability density intervals) of the posterior distribution based on multi-level models.

	Hunter recall data, all villages (n=11 villages)	Hunter recall data, subset of villages with village monitoring (n=7 villages)	Village-based monitoring data (n=7 villages)
Intercept[a]	6.0 [4.5,8.0]	7.3 [6.0,8.8]	3.0 [2.4,3.6]
Hunter-level variance	1.7 [1.5,1.8]	1.8 [1.6,2.1]	1.1 [1.0,1.2]

Village-level variance	1.7 [1.4,2.3]	1.1 [0.9,1.3]	1.3 [1.1,1.6]

[a] intercept represents estimated catch (number of animals killed) for 3.2 day trip, averaging over hunter- and village- variation

To assess whether apparent differences between villages were consistent across survey methods, average catch per day for villages, from village-based monitoring data, was modelled as a predictor of catch from hunter recall data (see main text). There was little evidence for a positive relationship between mean catch per village according to village-based monitoring and catch recorded by hunter recall (Figs S6, S7).

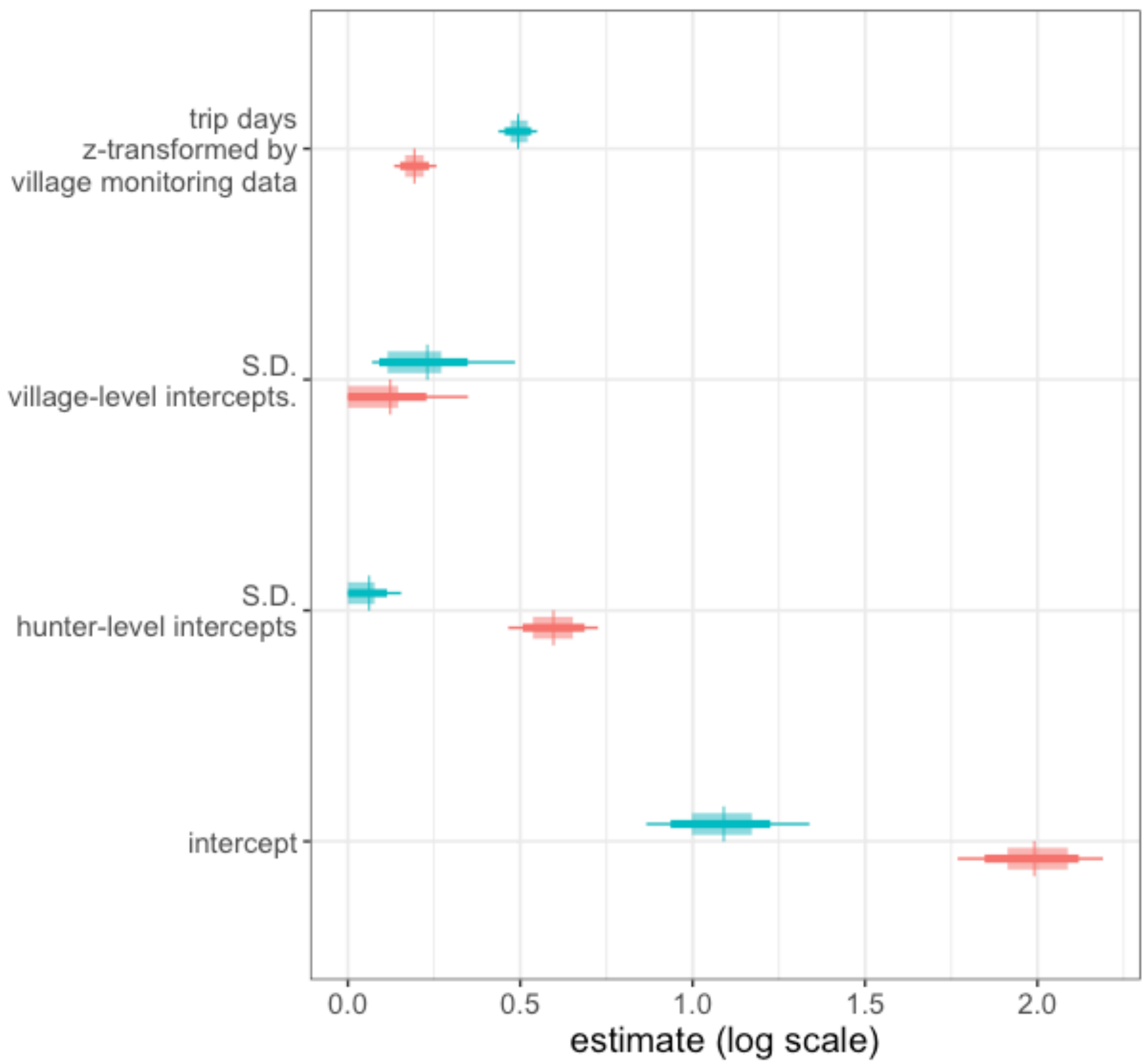


Fig S5. Posterior parameter estimates from models of catch from two data sources: village-based monitoring (blue, above grid-lines) and hunter recall (red, below grid-lines), using only data collected from villages with both methods. Posterior means are shown with 67%, 87% and 97% highest density intervals. Results are shown for Poisson multi-level models, fit separately to each data source, with a fixed effect for trip duration (centred and scaled by the mean and standard deviation of the village-based monitoring observations), and varying intercepts for villages and hunters.

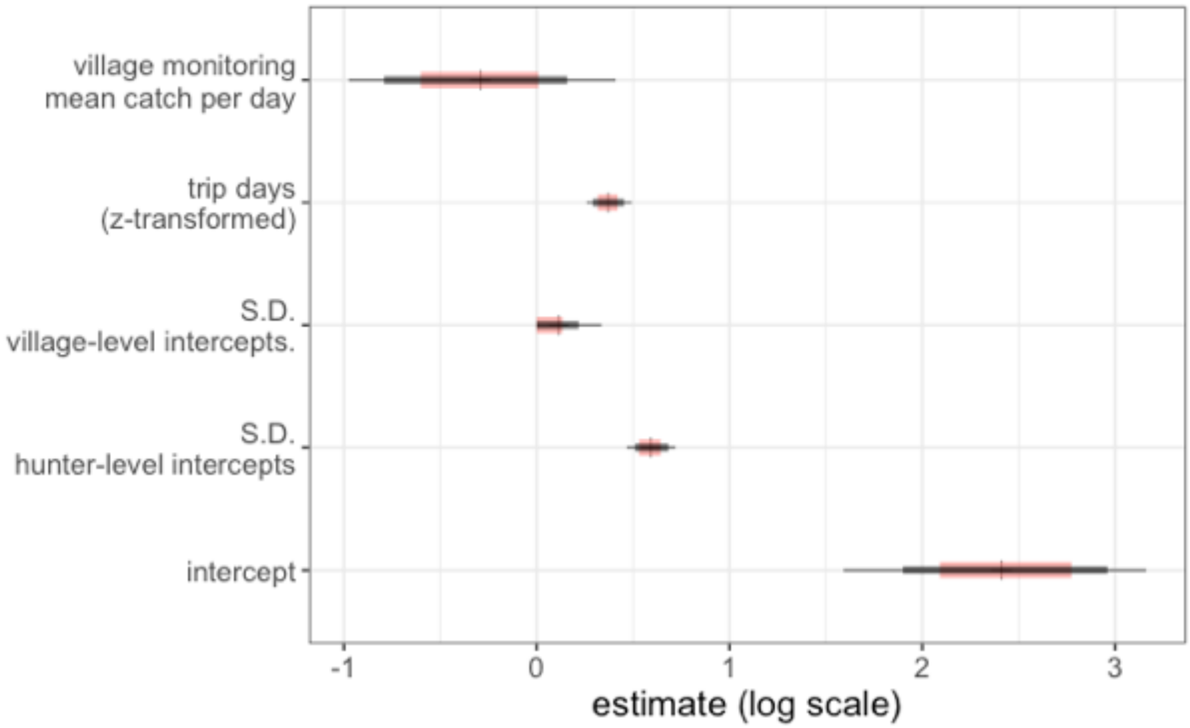


Fig S6 Parameter estimates for model fit to hunter recall data (n=140 hunting trips; 106 hunters) in villages where village monitoring was conducted (n=7), with village-based monitoring mean catch as a predictor variable. Mean posterior values are shown with shading indicating the 67%, 87% and 97% highest density intervals.

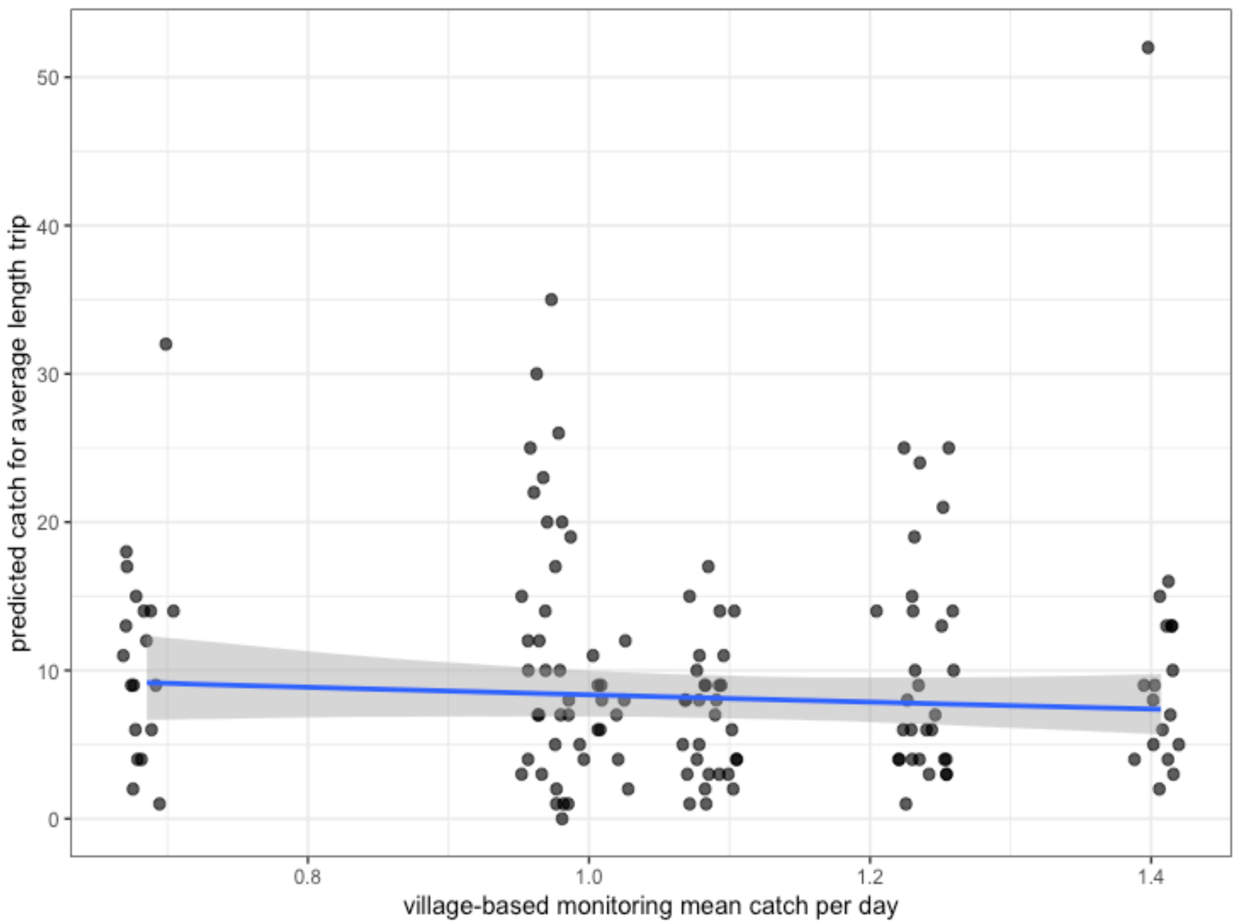


Fig S7. Predicted relationship between mean village catch per day according to village monitoring data and predicted catch from hunter recall data, averaging over hunter and village level variation.

Model validation

The fit of models was assessed visually, using the shinystan application (Gabry et al, 2018; http://mc-stan.org/shinystan) and bayesplot package (Gabry & Mahr, 2019). Comparisons of observed and expected values for best-fitting models of catch are shown in Figs S8 & S9.

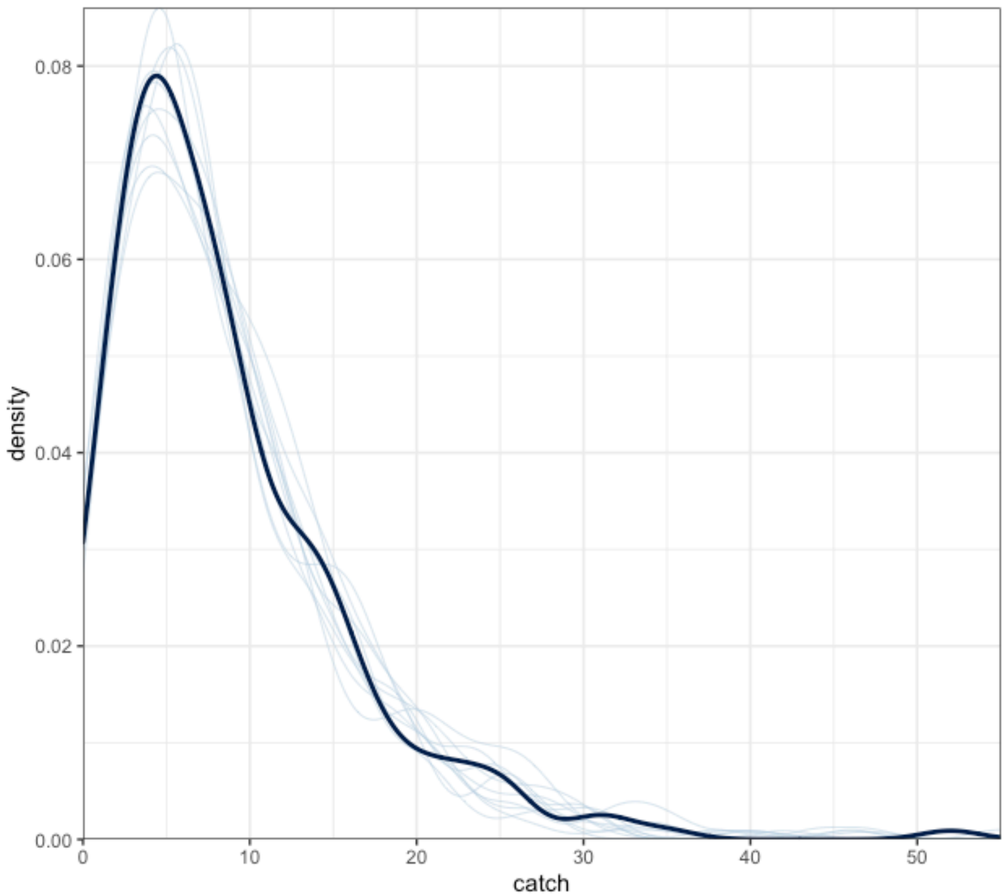
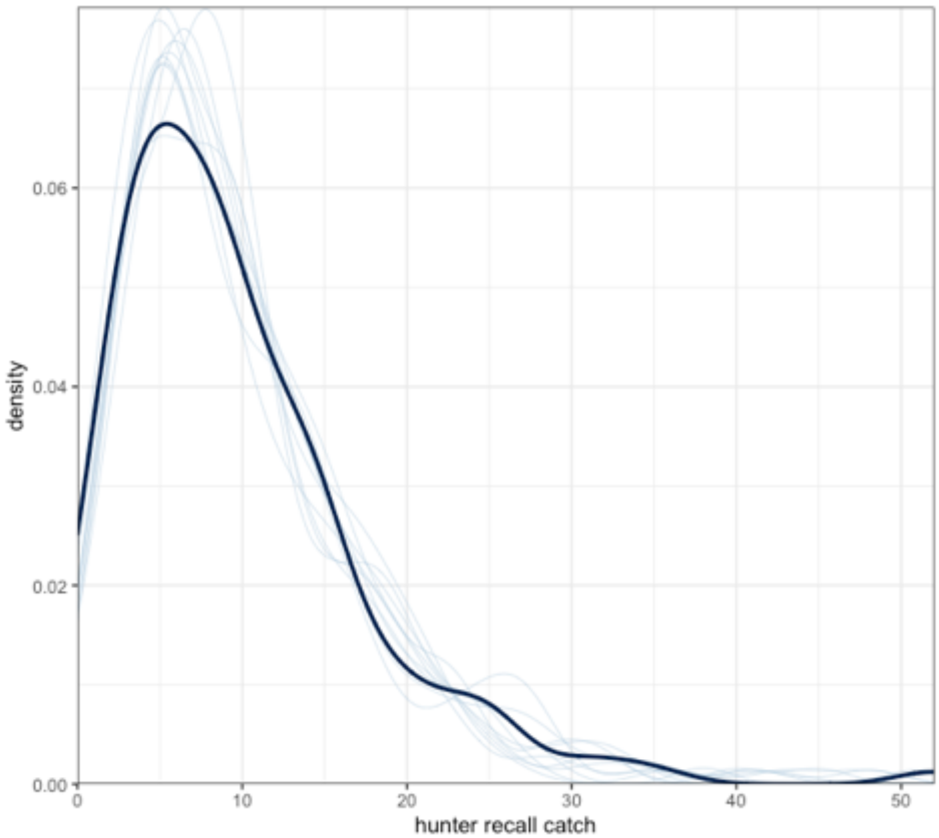
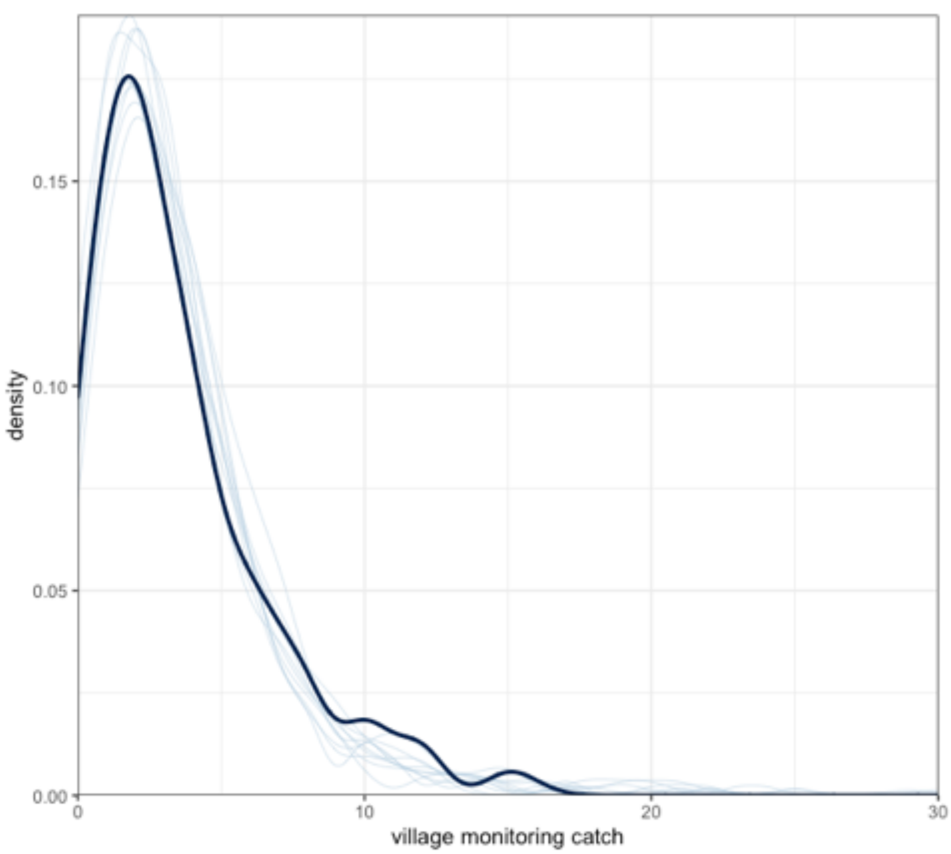


Fig S8. Visual assessment of model fit based on distribution of observed values (bold line) and expected values from 10 samples from the posterior (blue lines) from the best-supported model of hunter recall data (n=252 observations) with covariates method, trip accompaniment, season and an interaction term for method and season.



density
0.06
0.04
0.02
0.00
0
10
20
30
40
50
hunter recall catch



density
0.15
0.10
0.05
0.00
0
10
20
30
village monitoring catch

Fig S9. Visual assessment of model fit based on distribution of observed values (bold line) and expected values from 10 samples from the posterior (blue lines) from models of hunter recall data (top; n=140 trips) and village monitoring data (lower; n=384 trips) collected in the same villages and fit with a covariate for trip duration and varying intercepts for villages and hunters.

Literature cited:

Gabry, J., Simpson, D., Vehtari, A., Betancourt, M., and Gelman, A. (2018). Visualization in Bayesian workflow. *Journal of the Royal Statistical Society Series A*, accepted for publication. arXiv preprint: http://arxiv.org/abs/1709.01449.

Gabry J, Mahr T (2019). "**bayesplot**: Plotting for Bayesian Models." R package version 1.7.0, mc-stan.org/**bayesplot**

Vehtari A, Gelman A, Gabry J. 2015. Pareto smoothed importance sampling. arXiv preprint arXiv:1507.02646.

Chapter 7. Discussion

The work in this thesis focusses on understanding the diversity of resource users in a remote forest edge region of Liberia and then applying tools from social sciences to target behaviour change efforts more effectively . I aimed to describe a hunting system in Liberia and to advance conservation practices in three key areas. First, I aimed to gain an understanding of hunting and trading behaviour in the context of social relationships and financial incentives. Second, I explored tools to improve interventions aiming to reduce hunting by differentiating potential target groups and, third, I examined ways to measure resource-use behaviour that can account for potential biases, yet remain straightforward to implement.

To build an understanding of the hunting system, I found valuable insights were gained by considering the social context of behaviour, which revealed that inter-personal relationships were influential and that different incentives operated for hunters and traders (Chapter 3). While some traders were influenced by confiscation of meat at roadblocks, hunters cited time demands of agricultural activities as an important constraint on hunting. Such findings suggested that designing different interventions to be targeted toward each of these groups may improve outcomes.

The value of better-targeted interventions was further supported by results of ‘audience segmentation’ (Chapter 4), a marketing approach to differentiate groups across multiple traits, such as socio-demographic and behavioural characteristics (Albrecht, 1996). Audience segmentation identified distinct patterns in livelihoods and hunting behaviour with implications for how interventions might be better targeted toward different groups of hunters. For instance, training to improve yields from cocoa was identified as an appropriate approach for the group characterised as “local trappers”. However, such an intervention could be less effective in reducing hunting among the “non-local gun-hunter” group, since very few gained income from cocoa farming.

To monitor changes in behaviour, I demonstrated the potential value of the bean method (Lau et al., 2011) in addressing the problem that sensitive or illicit activities may often be under-reported (Chapter 5). This technique provided evidence that trading behaviour had decreased over a 2-year period, a finding which was supported by local anecdotal reports. I further explored ways to improve understanding of resource-use patterns by examining the quality of data used to describe harvest rates (Chapter 6). Harvest data can underpin resource management decisions and is often used in monitoring, as well as being fundamental for defining target groups for the project to engage with. Comparing two harvest data survey methods, I found that results differed substantially due to issues such as non-random sampling of hunters and reporting error. This finding showed that understanding the range of hunters' behavioural profiles could improve survey designs, and that harvest estimates require cautious interpretation in hunting studies.

Taken together, my results show there are valuable opportunities to improve design of conservation interventions by focussing more on who they are aimed at, and how to accurately measure and monitor people's behaviour. Tools from the social sciences, including marketing, can be adapted for site-based conservation management and are a valuable resource for conservationists seeking to improve behaviour change outcomes. In the following discussion, I first consider the local implications of my findings for the GolaMA project site, in terms of 1) opportunities to improve intervention designs, and 2) appropriate tools to monitor hunting and trading behaviour which address data quality issues. I then discuss the wider implications of our work for conservation practice, in terms of understanding, influencing and monitoring resource-use behaviour.

Implications for conservation at the GolaMA site

This study is the first to describe a rural hunting system in Liberia. The system shares many similarities to hunting systems from across West and Central Africa, for example, that traders are mainly women, in the diversity of harvested species, and in the high variability between hunters in terms of effort and hunting income (e.g. Bachmann et al., 2019; Coad et al., 2010; Foerster et al., 2012; Kumpel, 2006). The main conservation strategies applied across the Gola Forest, such as protected areas, law enforcement and livelihood-support interventions (Chapter 2) are also widely used elsewhere (e.g. Brooks et al., 2013; Cronin et al., 2017; Tranquilli et al., 2014). The GolaMA site is, however, within one of the largest forest tracts remaining in the upper Guinea Forest biome (Christie et al., 2007) and has low human population density and deforestation rates compared to elsewhere in the region (Hansen et al., 2000 accessed via www.globalforestwatch.org). In addition, the presence of diamond and gold deposits exerts an important local influence on livelihood strategies. Thus, while the discussion below explicitly considers the GolaMA site, it inevitably touches on topics that are likely to be relevant for hunting systems elsewhere. I discuss two central management implications of my work: (1) how behaviour change interventions might be improved and (2) appropriate methods for monitoring hunting and trading activity.

Opportunities to improve intervention design

Effectively targeting livelihood support interventions

At the GolaMA project site, I found livelihood-support programmes and hunting regulations could be improved by targeting distinct needs and motivations of different resource-users, rather than taking a "one-size-fits-all" approach. For instance, it seems likely that hunters and traders respond differently to law enforcement and agricultural programmes (Chapter 3), while patterns of citizenship, hunting and access to income from cocoa or palm plantations could determine which type of hunters become involved in livelihood support programmes (Chapter 4). Managers at the GolaMA site use several types of interventions aiming to reduce hunting pressure in community-managed forests. Conservation activities encompass livelihood-based approaches, establishment of governance structures and community-level regulations and enforcement, which sit alongside protected area management across the wider landscape. My work suggests that the process of defining target groups could provide a useful framework for decisions about where and how to implement these various types of interventions.

One of the key challenges facing managers in GolaMA, as elsewhere, is balancing the livelihood needs of people against the goal of safeguarding wildlife (Wicander and Coad, 2015). This study found high livelihood dependence on bushmeat: approximately 40% of households were involved in hunting or trading, and bushmeat represented the largest income source for a majority of hunters (74%) and traders (78%). Bushmeat has also been shown to play a substantial role in rural diets, both in the study site and across Liberia (GolaMA, unpublished; Ordaz-Németh et al., 2017), which underscores the need to ensure people's well-being is not negatively impacted by restricted access to wildlife resources.

My work using segmentation approaches (Chapter 4) suggests that both equitability and effectiveness of livelihood interventions might be improved by distinguishing different types of resource users, and using this as a basis for targeted intervention design. The results of Chapters 3 and 4 highlight potential for better targeting of women and non-local residents who may have specific livelihood needs. For instance, traders, many of whom were women, can incur substantial financial losses due to confiscation of meat at roadblocks and may abandon their activities as a result (Chapter 5). Added to this, the range of non-bushmeat income sources available to female traders may be constrained by cultural norms and barriers, such as access to education (Leach, 1994). In some hunting systems, woman can play a powerful role in motivating hunters, for instance, by refusing to sleep with partners who do not hunt, or openly disrespecting non-hunters (Lowassa et al., 2012), and insights into hunter-trader relations in GolaMA (Chapter 3) suggest similar mechanisms may occur. Thus, explicitly considering female traders in designing interventions could help ensure hunting restrictions are effective without disproportionately impacting women. Additionally, a better understanding of women's roles in the bushmeat system could help identify barriers for behaviour change, and may reveal opportunities to leverage existing social mechanisms (Leisher et al., 2016).

In designing well-targeted livelihood interventions at GolaMA, as elsewhere, there is also a need to better understand potential feedback mechanisms between different income generating activities (Larrosa et al., 2016). For example, of the livelihood programmes offered by the project, the small loans scheme was particularly well received by women and was seen by many as a way to expand or start small business enterprises selling petty goods (*pers. obs*). I found many female bushmeat traders gained additional income from petty goods businesses (Chapter 3), suggesting that credit schemes could be a promising way to support non-bushmeat livelihoods for female traders. However, transportation costs associated with running small business enterprises were often offset by sale of bushmeat in the urban markets where goods are purchased. With high transportation costs, travelling 'empty-handed' to the city to purchase stock for a small business required a large amount of capital. Traders could get around this by transporting meat to sell at the urban market, which generated cash that could be re-invested into purchase of goods (Chapter 3). Studies elsewhere suggest such patterns are not unusual (Bachmann et al., 2019; Cowlishaw et al., 2005; Kümpel et al., 2010). Thus, an increase in petty goods enterprises could also increase incentives for bushmeat trading. So, while credit schemes may be important to improve socio-economic conditions of female traders, robust mechanisms are needed to ensure loans are not reinvested into bushmeat activities.

Another potentially vulnerable group, with distinct livelihood needs, could be resource users of non-local ancestry such as settlers from elsewhere in Liberia or transient migrants. Audience segmentation results showed that non-local citizenship was a clear factor that differentiated potential target groups at GolaMA (Chapter 4), and it also seems likely that non-locals can be under-represented in hunting studies more generally, due to sampling biases. Under the community-based management framework being implemented at GolaMA, decisions over resource use rights were to be placed in the hands of local management bodies who were likely to be mainly comprised of indigenous citizens. As in other settings, this local governance system could disempower non-local residents (Agrawal and Gibson, 1999; Suich, 2013). Citizenship could be associated with specific barriers for livelihood activities and income generating opportunities, such as land tenure security (Corriveau-Bourque, 2010). At GolaMA, non-local ancestry was tied to patterns of hunting behaviour, experience of law enforcement and livelihood portfolios with non-locals typically having high exposure to law enforcement and low probability of income from plantation crops such as cocoa or oil palm. This was especially true for the 'non-local gun hunter' group, a potentially important target group with high hunting impacts and few other income sources (Chapter 4).

Clearer understanding of the underlying processes affecting livelihood decisions of local versus non-local citizens could help improve interventions. For instance, training of cocoa farmers and provision of equipment to process palm oil are a central component of livelihood support activities in the Gola landscape, among other financial mechanisms (e.g. Bulte et al., 2012; Voors et al., 2011). Our findings suggest it may be important to complement these programmes with activities specifically tailored to suit non-local groups, for instance, bee-keeping or annual agriculture may be more appropriate as these can deliver returns after much smaller investments of time and resources. Further work to understand which types of hunters participate in different livelihood schemes, and the extent to which their behaviour is altered as a result, is needed to develop more effective and equitable livelihood programmes. The groups identified through the segmentation exercise (Chapter 4) provide a useful starting point to monitor behaviour-change more strategically in order to address these knowledge gaps.

A broader perspective on potential target groups

The scope of this work was largely focussed on hunting and trading behaviour in the GolaMA forest communities. However, the full supply chain extends to consumers and urban distributors and a broader perspective on where to target interventions could be valuable. Informal reports in GolaMA suggested that a single, trusted buyer in Monrovia played a disproportionate role in facilitating and encouraging commercial exploitation of bushmeat resources (Chapter 3). Targeting such an individual could be an effective means to disrupt the illegal trading system, as a high proportion of traders relied on their trust-based personal relationship to this contact, built over several years. Currently, efforts to reduce hunting and trading often focus on rural forest communities where hunting takes place, or on urban consumer populations (Bachmann et al., 2019). However, my work in GolaMA suggests that at least in some settings, there could be an overlooked group of relatively few individuals who buy and redistribute meat from many hunters or traders. Such individuals may act as financial sponsors, with sufficient capital to advance loans to hunters and traders, thereby reducing economic risks for those closer to the supply end of the chain. Anecdotal reports (Chapter 3) suggested that several hunters and traders were actively recruited and incentivised by the same individual. The extent to which this pattern is found elsewhere remains unclear, although a large-scale study across the supply chain around Tai National Park in Ivory Coast, found no such structures (Bachmann et al., 2019).

Effective behaviour change mechanisms

To develop future interventions at GolaMA, it will be important to clearly identify the mechanisms by which livelihood support programmes are expected to influence hunting behaviour. In this regard, the finding that there were relatively large financial returns from bushmeat for both hunters and traders (Chapter 3) indicates hunting reduction is unlikely to be achieved simply by making 'alternative' activities more profitable than hunting. It also was found that non-economic factors, such as inter-personal trust between hunters, traders and urban distributors, could create social barriers for behaviour change which may not be addressed by interventions that focus on economic drivers. Nevertheless, the monitoring results (Chapter 5) showed that financial factors can play a role in behaviour-change at GolaMA, whereby financial risks due to law enforcement could make 'safer' income sources more attractive, but these may operate differently for hunters and traders.

The apparent decrease in bushmeat trading over the 2-year study period suggested that road-block confiscations can be an effective disincentive for some traders (Chapter 5), but the patterns in hunting activity suggest that law-enforcement efforts may need to be highly coordinated across trade-routes to effectively reduce hunting pressure. This was consistent with findings from Chapter 3, in which traders reported meat confiscation to be a major challenge for making profit from meat trading. Studies elsewhere have similarly shown perceptions of law enforcement can act as a deterrent for illegal wildlife use (Chen et al., 2018). Several residents observed that hunters catch was diverted along alternative routes in response to increased meat confiscation at the roadblock to Monrovia. Thus, law enforcement efforts could reduce bushmeat hunting by introducing high financial risk but this needs to be coordinated across the landscape. Strengthening the transboundary collaboration between the Governments of Liberia and Sierra Leone (Hillers, 2013) could be an important way to maximise the impact of law enforcement efforts and reduce illegal hunting and trading of wildlife.

Improving intervention design at GolaMA: an overview

Overall, my work suggests intervention design at GolaMA can be improved by identifying how specific groups of resource users might be targeted more effectively. Livelihood decisions of key groups, such as local and non-local citizens, and female traders, need to be better understood to ensure interventions are effective and equitable. Potential feedback mechanisms between hunting and other income generating activities also need to be identified to avoid unintended consequences of tools such as small loans schemes. As with many hunting systems, effective strategies to reduce hunting pressure on wildlife are likely to be multi-faceted (e.g. Bachmann et al., 2019; Van Vliet and Nasi, 2008) and require coordination across law enforcement and livelihood support tools. Going forward, intervention designs will benefit from better integration of behavioural theory into the processes of developing and monitoring interventions (see Jenks et al., 2010). This would help build understanding of how different groups of resource users respond to behaviour change mechanisms, so that these can be more effectively targeted.

Appropriate tools to monitor intervention impacts

The bean method as a potential monitoring tool

An important challenge for GolaMA managers seeking to improve interventions is how to evaluate behaviour change. Communities should lead the process of developing monitoring systems that aim to support local management to ensure monitoring methods are fit for purpose and can be sustained (Turreira-García et al., 2018). However, many techniques used to measure sensitive behaviours are complex and can be hard to use (Hinsley et al., 2019; Lensvelt-Mulders et al., 2005). I found the bean method was suitable for implementation by local communities as it was straightforward to design and administer surveys, equipment could be obtained locally, and raw results could be interpreted without statistical training. Hunting was not found to be a highly sensitive issue in GolaMA, but sensitivity could increase in the future, for example, due to the introduction of community forest regulations that are currently being developed. The bean method provided a questioning format that allowed resource users to report activities without sharing their answers openly, and as it had few drawbacks in terms of costs or time, it could be a useful monitoring tool to complement direct questions.

At the time of writing in May 2020, community forest management plans for the two clans participating in the GolaMA project had not been fully developed. Depending on the desired management outcomes that are ultimately agreed, a simple monitoring programme to assess behavioural prevalence at regular intervals could be appropriate (e.g. annually or as often as resources allow). Resource-permitting, such a programme could implement the bean method alongside direct questions during a household survey, as demonstrated in Chapter 5. To reduce costs it may be possible to explore alternative administration modes such as group interviews (e.g. following Lowndes et al., 2012), although close attention to sampling will be important to interpret results. Organisations supporting community-based management in GolaMA should consider conducting workshops or training events designed to support communities in developing appropriate monitoring tools, presenting the bean method as a potentially useful and flexible method.

There is also a need across Liberia for a more widely implemented monitoring programme aimed at determining longer term trends in bushmeat use. Such a programme might be supported by external agencies using methodologies which are harmonised at a national or regional scale. The bean method could also play a role in such wider monitoring efforts, as a rapid means to assess prevalence of potentially sensitive behaviours. However, the method is limited in terms of being able to assess underlying patterns at the individual-level. In general, reliable information about resource use can be hard to obtain so drawing information from several sources is key to gaining a robust insight into patterns (Anglewicz et al., 2013). As an alternative questioning format that can be compared to direct questions, I found bean method was useful to help gauge response reliability (Chapter 5), but the overall extent to which respondents are likely to give truthful answers is not well understood (Cerri et al., 2017; Lau et al., 2011). Other types of information, such as patrol or law enforcement records, or ecological surveys, should therefore be sought wherever possible as a means to triangulate results (Gavin et al., 2010; Keane et al., 2011). Ultimately, monitoring approaches will be most valuable where information about prevalence can be coupled with insights into underlying drivers of behaviour (Jenks et al., 2010).

Use of harvest data for monitoring

Previous work has suggested that harvest data metrics, such as catch per hunter-day, and mean body mass of prey, might be useful to understand patterns of wildlife use and could be practical in community-based management settings (Ingram et al., 2015; Marrocoli et al., 2019). However, my work at GolaMA adds to a substantial body of literature (e.g. Dobson et al., 2019; Keane et al., 2011; Knapp et al., 2010; Maunder et al., 2006; Rist et al., 2010) showing that harvest rate metrics are susceptible to several sources of bias which are hard to minimise or quantify. As such, catch data might be most useful when it is viewed alongside several alternative data sources, rather than as a standalone monitoring tool. Following the establishment of conservation management plans in the GolaMA site, the introduction of hunting regulations will mean that harvest surveys may be unable to obtain information from hunters lacking permits, or those operating outside designated hunting zones. This constraint will add to sources of bias already present, and further limits the degree to which harvest data can be expected to reveal patterns across the wider hunting system (Rist et al., 2008).

Despite these limitations, harvest assessments could be important from the perspectives of communities and managers may wish to incorporate information about hunters catch for purposes such as setting quotas or permit fees (Marrocoli et al., 2018). To design future harvest rate surveys at GolaMA, my work suggests it is important to ensure: sampling captures the range of hunting behaviour and trip lengths; that hunting effort is quantified as thoroughly as possible; and that potential reporting error is minimised. Results can be better interpreted if potential sources of bias are identified, so further work to help to clarify relationships between catch and factors which may be unevenly sampled, such as hunting base or trip duration, would be valuable.

Recommendations going forward

The effectiveness of ongoing work at the GolaMA project site could be improved by better understanding of the barriers and incentives underpinning livelihood decisions, better targeting of interventions and robust monitoring of outcomes. The foundation for all of these three areas is a broader and deeper understanding of social structures in the system and the variation that exists within and between groups when it comes to resource use behaviour. My thesis provides a starting point for developing this understanding1 and based on its findings I suggest the following priorities for future research and conservation activities in and around the GolaMA site.

1. **Evaluate effectiveness of interventions:** Conduct a follow-up survey to evaluate the effectiveness of the GolaMA interventions in terms of influencing people's behaviour. This should focus on identifying the barriers and mechanisms which facilitated or prevented behaviour change for different groups of people, and how features of intervention design and implementation promoted or inhibited livelihood decisions. Survey methods could include semi-structured interviews and focus group discussions designed to differentiate the experiences of key groups such as local versus non-local citizens. Specific topics to explore could include potential unintended feedbacks between hunting and small loans schemes, and whether hunting restrictions resulted in negative economic impacts on vulnerable groups.

2. **Adaptive intervention design:** Establish of an adaptive process of intervention development such that the results of a GolaMA follow-up survey can influence the design or implementation of future conservation projects in or around the site. The experience of RARE Pride Campaigns demonstrates that effective tools can be developed through an iterative process of applying, evaluating and then re-designing interventions (Jenks et al., 2010), and a similar model could be helpful in GolaMA.

3. **Monitor resource use:** Support communities to develop a monitoring programme that can assess patterns of resource use in each of the GolaMA Community Forests. The methods which are most appropriate will depend both on the specific questions that communities wish to address and the resources available. However, where possible information should be obtained in more than one way, for instance by applying the bean method alongside direct questioning formats, or from several sources, for instance, by pairing hunters' reports of effort, with sales of gun cartridges, or comparing catch composition to consumption surveys or camera trap records (e.g. Marrocoli et al., 2019).

Valuable insights are likely to come from local knowledge and informal observations, so capturing these within any monitoring system could be a cost-effective approach.

4. **Support transboundary law enforcement alongside livelihood support:** Support coordinated transboundary law enforcement efforts, particularly confiscation of meat at road-blocks, and explore opportunities to identify and bring to account any influential commercial buyers that may have a disproportionate role in driving illegal hunting. Financial risks from roadblock confiscations appeared to be effective in reducing bushmeat trade, and consistent, coordinated efforts could be a powerful tool in making bushmeat less economically appealing. However, the long-term effectiveness of this approach depends on the availability of other income generating opportunities for rural hunters and traders, and ensuring that enforcement is enacted in an ethical, and socially just manner. Resourcing and training across law enforcement agencies is needed in both Sierra Leone and Liberia for effective and equitable implementation of wildlife laws.

5. **Monitor long-term trends in hunting pressure and assess sustainability for key species:** Work towards developing national or regional-scale monitoring systems aimed at identifying trends in hunting pressure over long timescales (years to decades). Ideally, such a monitoring program would enable assessments of hunting patterns associated with different land management regimes and conservation interventions. It is also important to evaluate sustainability of hunting for different species, in order to design rules which can protect vulnerable species without causing unnecessary hardship on those who depend on bushmeat. Measures describing hunting and trading prevalence or frequency are likely to be more reliable metrics than catch per unit effort, but several sources of information should be evaluated if possible. Consistent reporting of law enforcement data, such as confiscation records, could be useful to support better monitoring. More generally, there is a need to increase the technical capacity within government agencies and civil society organisations to support the management of national or regional databases describing resource use. To support the design of effective rules, it is

Wider implications in the field of conservation

The research presented in this study addresses practical challenges faced by conservationists seeking to understand and influence people's behaviour in relation to the hunting and trading of bushmeat. Although the work focuses on one site in West Liberia many of the results have wider relevance across diverse conservation settings. Key findings relate to the following themes which will be discussed below: (1) the value of mixed-methods approaches for understanding social-ecological systems from the perspective of resource users; (2) the need to consider diversity in human populations to define target groups; and (3) the challenges associated with accurately measuring behaviour. In exploring these themes, I look at two tools, audience segmentation and the bean method, which have been largely overlooked in conservation, but which could be appropriate for many settings.

Understanding resource use behaviour

While there have been significant moves to integrate social science techniques into conservation practice (Bennett et al., 2016a), many of those working in conservation lack technical skills and training when it comes to understanding and influencing human behaviour (Robinson et al., 2019). Consequently, conservation efforts may be hampered as social science techniques are not exploited to their full potential (Moon et al., 2019). The study presented here illustrates that the integration of social science techniques into standard conservation practices can be extremely useful, and that conservationists can gain broad insight into behavioural systems by applying a range of data collection approaches.

I found that focus group discussions and open-ended interview questions provided valuable context for understanding social elements of a hunting system (Chapter 3) and for interpreting apparent changes in behaviour (Chapter 5). This is consistent with several other studies of hunting systems, where mixed method approaches have revealed complex social and political structures across bushmeat supply chains (Bassett, 2005; Cowlishaw et al., 2005; Schulte-Herbrüggen et al., 2013; Van Vliet et al., 2015) and have helped identify motivations, attitudes and cultural nuances which can be fundamental for designing effective interventions (e.g. Katikiro, 2016; Nilsson et al., 2016). Techniques from social science disciplines, such as psychology, may be particularly well suited to reveal perspectives of resource users and the diverse attributes of different groups (Osbaldiston, 2013; Saunders et al., 2006; Selinske et al., 2018), which marketing tells us should be placed at the centre of intervention design (McKenzie-Mohr, 2000). Encompassing both qualitative and quantitative approaches, social science tools can help describe the social landscapes of resource use systems and identify non-economic factors influencing livelihood decisions, such as social norms, power structures and information flows (Ajzen, 1996; Schultz et al., 2007).

A clear understanding of resource use behaviour is valuable for defining target groups, as a key concern is selecting appropriate variables by which to differentiate people (McKenzie-Mohr, 2000). As such, segmentation analyses can be seen as part of an iterative process which uses mixed methods to identify potential drivers of behaviour, clustering to evaluate patterns between drivers and monitoring to assess which drivers are relevant for behaviour change. For instance, future segmentation exercises could draw on the qualitative and quantitative insights gained from the present study, to incorporate variables relating to attitudes toward the risks of meat confiscation, land tenure concerns of local versus non-local citizens, or financial and non-financial relationships between hunters and traders. When it comes to monitoring conservation behaviour, information from varied sources can provide the necessary context to interpret apparent trends. This was demonstrated in Chapter 5, where anecdotal reports about traders' responses to law enforcement were a key source of information for assessing the reliability of apparent decreases in bushmeat trading. The susceptibility of some behavioural datasets to numerous sources of error and bias, illustrated in my comparison of harvest rate estimates (Chapter 6), further demonstrates that interpretation of behavioural studies may be greatly improved when results are viewed alongside other information sources.

The use of tools that generate qualitative data was limited in my study, but these could have generated deeper insights into the hunting system. One constraint was a lack of resources to train local researchers who were unfamiliar with qualitative methods. Qualitative data collection techniques can demand specific research skills and a higher level of literacy than some quantitative methods, and this presented a barrier for their use in the rural Liberian setting. Added to this, the development of many tools from the social sciences, such as psychological scales to evaluate risk preferences, has been heavily biased toward populations of high-income countries making them inappropriate in most other settings (but see Charness et al., 2013). Building scientific research capacity in under-resourced countries has been identified as a key priority for conservation (Atickem et al., 2019), and evidently such training programmes need to focus on social science skills as well as ecological disciplines (St John et al., 2014).

Defining target groups

There is a growing momentum to bring social marketing tools more squarely into standard conservation practice, and others have made compelling arguments that this could improve demand-reduction campaigns (Greenfield and Veríssimo, 2019; Olmedo et al., 2017), use of flagship species (Verissimo et al., 2011), reduction of human-wildlife conflicts (Veríssimo et al., 2019) and conservation messaging (Kidd et al., 2019). My findings demonstrate that the nascent field of 'conservation marketing' is similarly relevant for site-based management, and that tools to define target groups and monitor behaviour can be extremely valuable in rural sites where the type of data which can be collected may be constrained. Proponents of conservation marketing have identified that defining target groups is an important step for improving behaviour-change outcomes (Kidd et al., 2019; Verissimo et al., 2011; Wright et al., 2015). My work suggests that audience segmentation can be an effective tool to achieve this (Chapter 4), supporting a recommendation that it should be more widely adopted as standard practice.

The socio-economic wellbeing of resource users is an important concern for achieving sustainable management of natural resources (Lele et al., 2010). However, designing interventions that achieve socio-economic goals alongside conservation is challenging (Wicander and Coad, 2018). Results from Chapters 3 and 4 suggest that both equitability and effectiveness of livelihood interventions might be improved through distinguishing different types of resource users, based on factors such as citizenship, gender and livelihood portfolios, and using groups' profiles as a basis for targeted intervention design. Resource users vary in terms of how conservation restrictions could impact their livelihoods and the barriers they face in accessing alternative income sources (Coomes et al., 2004; Sunderland et al., 2014); segmentation approaches could help managers evaluate the needs of potentially vulnerable groups and identify mechanisms to influence resource-use behaviour more effectively.

There are a large number of analytical approaches to audience segmentation and these vary greatly in their complexity and assumptions (e.g. Boslaugh et al., 2005; Wang, 2010). My findings support the use of multi-variate techniques to group people according to multiple traits rather than a single characteristic. This approach is also favoured by marketers and a large body of literature describes segmentation methods (e.g. Schmid et al., 2008). One of the key elements for successful segmentation is choosing appropriate variables, which requires a thorough understanding of the system and the factors which influence responsiveness to interventions (Barber et al., 2012). Unfortunately, a good understanding of the ways different people respond to conservation interventions is currently lacking, and addressing this knowledge gap is challenging (Junker et al., 2017; Veríssimo, 2013). Building a robust evidence base for behaviour-change mechanisms will therefore go a long way to enable conservationists to leverage tools such as audience segmentation.

Measuring behaviour

My findings highlight the challenges of obtaining reliable information about behaviour and reiterates the usefulness of specialised techniques from the social sciences for conservation (Nuno and St. John, 2015). Response reliability, the degree to which people give consistent answers to the same question, is given relatively little attention in conservation studies but can be an important source of measurement error (Schwarz and Oyserman, 2001). Parallel use of alternative questioning formats, as I demonstrated with the bean method, may be a useful way to gauge response reliability.

The simple format of the bean method suggests it could be readily adapted for different types of uses, and our extension of the method to answers with more than one category demonstrates its flexibility. Future applications could explore alternative administration modes, or ways to obtain different types of answers such as by using symbols to represent answers falling into distinct categories. Importantly, in the absence of a validation study (Bova et al., 2018; Lensvelt-Mulders et al., 2005) the extent to which the bean method encourages truthful reporting remains unknown and future work is needed to address this question. The literature on specialised questioning techniques contains a wealth of studies seeking to validate approaches and improve their performance (e.g. Böckenholt et al., 2009; Chang et al., 2018; Cruyff et al., 2016; Gingerich et al., 2016). Applying similar focus to the circumstances under which the bean method can be most effective, would support the development of this potentially useful tool. For instance, I found the time demands for training and administration were extremely low, suggesting that it may have strengths as a rapid assessment tool.

Information about harvest rates can be central to understanding resource use. For instance, in the present study, data describing hunters catch revealed which species were killed (Chapter 3) and contributed to differentiating potential target groups (Chapter 4). However, as I demonstrate in Chapter 6, obtaining representative samples in studies of resource use can be challenging and results can be skewed by several sources of bias (Tourangeau and Yan, 2007). This may be particularly true of hunting systems, which characteristically show high variability among both hunters and hunting trips (e.g. Rist et al., 2008), and where hunting regulations may introduce the added problem of social desirability bias (Gavin et al., 2010). Correlations among behavioural traits can lead to large biases if traits are non-randomly sampled. For example, hunters who achieved the highest catch were also likely to be based in remote forest camps that are relatively inaccessible to researchers. Therefore, understanding the full range of people's behavioural profiles could help reveal possible implications of non-random sampling, providing a further reason why this should be a priority for conservation programmes.

My results in Chapter 6 imply that comparisons or syntheses of resource use data from different sources, although these can be helpful to assess broad patterns (e.g. Ávila et al., 2017; Hudson et al., 2017; Ingram et al., 2015), may be flawed if biases associated with different data collection methods are not accounted for. Large-scale projects, such as the Agrarian Change Project (Sunderland et al., 2017) in which consistent methodology are applied across large spatial scales, may help minimise some sources of bias. However, data quality remains a challenge, and issues such as reporting error may vary across sites.

Summary

My study adds to arguments that conservation practice can be improved by adopting approaches which explicitly focus on human behaviour and the factors that promote behaviour change. I suggest that improvements to intervention design needn't involve complex or costly methods, but rather a shift in focus that takes in the diverse perspectives of resource-users and the factors which influence behaviour. The work presented here demonstrates how tools from the social sciences, including audience segmentation and the bean method, can be useful to improve targeting of interventions and to monitor potentially sensitive behaviour. The degree to which bias can affect datasets describing resource use highlights the need to base decisions on a range of information sources. Conservation outcomes could be improved by ensuring that complex drivers of human behaviour are captured in intervention designs and placed at the centre of efforts to influence how humans interact with the natural world.

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